PROJECT PATHFINDER

SPACE HUMAN FACTORS PROJECT PLAN

Fall 1988

PATHFINDER

Office of Aeronautics and
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National Aeronautics and
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SPACE HUMAN FACTORS

An Element in the Humans-in-Space Thrust

A Project Pathfinder Initiative

Office of Aeronautics and Space Technology

National Aeronautics and Space Administration

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SPACE HUMAN FACTORS PROJECT PLAN

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SPACE HUMAN FACTORS PROJECT PLAN

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1.0 INTRODUCTION

The principal thrust of the Pathfinder Program is to develop technologies that will enable the United States to explore planetary and lunar surfaces far beyond low earth orbit operations. A decision to mount such deep space explorations will be made, based on the developed technologies, by national authorities. NASA is currently studying a broad range of potential missions as part of the Pathfinder Program, especially manned missions to a Mars or Lunar base. Therefore, the presence of mankind in deep space, called Humans-in-Space, has become one of three principal thrusts in the technology development effort. This Project supports the Human-in-Space, as do EVA/Suit and Physical-Chemical Life Support projects.

The success of these missions will depend upon maximizing the unique contributions of the human crew to discovery and exploration, to the management of scientific information, and to the maintenance of the vehicle, its component systems, and the constructed or planetary habitat.

The Pathfinder Program encompasses a number of technical disciplines. These missions will require new and significant advances in technology in order to match people with systems and machines to a greater and more significant degree than needed in prior space activities.

The purpose of sending humans to the moon and Mars is human exploration, and support for this human role is information-intensive. Mission planners and designers must go beyond the concept of simply keeping the crew alive and functioning at some minimal level. The must go beyond merely utilizing the perceptual and cognitive capabilities of the crew, as important as these capabilities are in routine and emergency operations. The research proposed in this document seeks to augment unique human capabilities in the context of planetary exploration, focusing particularly on human-system interface improvements.

A significant increase in the understanding of human performance and behavior under simulated conditions of long duration space missions will be acquired. Systematic analysis of cognitive and physical performance and cooperative behavior in such missions will serve as the basis for computer-aided design tools, enabling consistent and correct application of human factors. Systems and technology requirements will be identified for human rated systems which support long term space habitation and operations, provide well designed man-machine interfaces, information handling systems, and health care systems. Man in the loop simulations will provide data and insights into human performance. For long-duration manned missions, where the habitable environment will be restricted for many months , the human interface environment will be the critical determinant of the crew's productivity and of the mission's success. The features of the environment with which the crew interacts will be changing as technology develops.

1.1 OBJECTIVES OF THIS PROJECT PLAN

The program goals are to have available by the early 1990's sufficient knowledge of the human factors of long duration space missions to permit good planning and subsequent mission success. The needs of the crew must be identified and met from the standpoint of effective use of, and confidence in, the spacecraft and any surface vehicles or facilities required. The knowledge base and tools to do this must be available to the design engineers and mission planners.

The Pathfinder Space Human Factors Research Plan has been developed during the past two years by a team of researchers and managers from the Office of Aeronautics and Space Technology, Ames Research Center, Langley Research Center and Johnson Space Center.

This document addresses the issue of human productivity from two directions. Productivity and comfort of the crew is an important consideration. Accordingly, tasks are proposed to evaluate crew interface factors and also to develop models of how the crew will relate to its environment and to predict the effectiveness of various designs.

The objective of this Plan is to provide to NASA (specifically the Pathfinder Program) a description of the technology developmental steps necessary:

> *to enable safe and productive human performance throughout and after long duration space flight and lunar/planetary missions based on a scientific understanding and selected demonstration of human capabilities, limitations, and adaptive changes.*

The Pathfinder Space Human Factors Research Program will develop the scientific and technological base to support the design, implementation, and evaluation of crew-support systems, which will substantially increase human-machine system reliability, productivity, and flexibility. This research program will develop computational tools for system design and evaluation, innovative operator interfaces, and multisensory systems for situation awareness and control.New methods will be developed for planning and modeling human-machine systems. The methods developed for task- and performance-modeling, and for the validation of human performance models, will provide a significant contribution to cognitive science and engineering.These techniques will support the development of advanced design tools for human-machine systems, and ultimately tools for flexible configuration and work-planning in such systems. These efforts will be closely coordinated between ARC, LaRC and JSC. The Space Human Factors Research Program also will be coordinated with work under the EVA/Suit elements of Pathfinder and other parts of the Humans-in-Space thrust.

1.2 PROJECT PATHFINDER OVERVIEW

The Pathfinder Project is directed by the Office of Aeronautics and Space Technology (OAST) with the objective of developing critical technology options for a range of possible future solar system exploration missions. A decision window in the 1994-1996 period is envisioned based on NASA's Office of Exploration's (Code Z) mission studies, so that specific decisions can be made to pursue one or more of the explorations, based on the technology development to date and the results of scenario studies.

Three principal technology thrusts are planned:

- Exploration technology includes all elements of autonomous exploration as technology demonstrators and precursors to manned exploration.

- Operations technology includes all anticipated planetary/lunar surface operations and the development of vehicle technology to transit and return safely.

- Humans-in-Space technology includes all technology necessary to permit humans to travel to, live, and work productively in the hostile environments of micro-gravity and planetary or lunar surfaces.

During the second five years of the project, prototypes of developed technologies will be fabricated and tested. The prototype subsystems will be integrated and undergo systems testing and evaluation in light of mission objectives. The ten-year Pathfinder effort will enable the timely development and qualification of flight hardware for a long-duration mission in the first five years of the 21st Century.

1.3 MISSION STUDIES AND TECHNOLOGY REQUIREMENTS

The Office of Exploration, Code Z, has been charged with the task of developing specific mission scenarios and to perform scenario studies.

As of the date of this report, initial efforts have identified manned missions from low earth orbit to:

- the Earth's moon for purposes of exploration on a continuing basis so that lunar resources can be used for solar system exploration;

- the Martian moon(s) for purposes of surveillance of the planet;

- the surface of Mars.

The following mission studies have been requested from the Office of Exploration (Code Z), and these have also been suggested as possible ad hoc studies to be conducted through the Space Sciences Technical Advisory Committee (SSTAC):

Comprehensive survey of human factors issues across all Pathfinder elements, focusing on

-- emergency human intervention requirements
-- telerobotic control requirements
-- supervisory control requirements
-- human-machine interface commonality requirements

Survey of past studies of human-machine function allocation schemes in military, space, and related analog environments, focusing on
- design principles for robust systems
- best use of humans vs. automated systems

Carefully indexed database of NASA's operational experience to allow scientists easy access to Mercury, Gemini, Apollo, Skylab, Shuttle, and Shuttle/Spacelab
- mission transcripts
- mission debriefings
- other raw data

Compilation of detailed data on Human-Machine Systems design issues surrounding error, confusion, conflict, accident, and unexpected system or ground/flight crew behavior, focusing on
- level of automation
- related training
- crew comments and criticisms
- design philosophy and constraints
- mode of human-machine interaction

Analysis of requirements for integrated planetary surface information systems to be used by manned and unmanned missions, focusing on
- U.S. and U.S.S.R. experience
- relative roles of humans and automation
- human interface requirements
- data communication requirements

The Office of Space Science and Applications, Code E, will be responsible for biomedical requirements for these scenarios. Topics to be addressed by Code E are described in a separate Project Plan. There are several tasks and sub-tasks in this Plan which interact with Code E studies and are so identified in Section 3.

1.4 TECHNOLOGY ASSESSMENT

NASA's past research and development efforts and its collective experience in space operations provide a firm basis to evaluate technology requirements for the crew. The safe and productive performance of the crew, individually and collectively, requires sustained human productivity. Human productivity and crew performance are joined such that we can define human performance as the sustained performance of all assigned crew functions in a timely and accurate manner, with sustained quality of output and of life throughout the mission. Crew performance support needs and mission requirements are the basis for the technologies developed in this Plan.

At present, the design of the spacecraft for operations and maintenance by the crew is a process characterized by multiple engineering and operations tradeoffs, iteration of design, use of mock-ups, paper analyses, and computer modeling. Efficient and effective methods for modeling human performance (e.g., physical, cognitive and perceptual activities, data about human performance under varying gravity conditions, definition of crew needs for living and working on planetary/lunar surfaces and in space, etc.) are needed to support technology development. Computer models of physical, cognitive and perceptual capabilities and limitations of astronauts should be extended from their current state to incorporate these new requirements.

Since the early 1960's a great deal of research on human performance modeling has been supported by agencies such as the Department of Defense (ARPA, ONR, ARI, AFHRL), the Department of Education, the National Science Foundation, the National Institutes of Health, the Nuclear Regulatory Commission, and NASA. In addition, related research on human-machine interaction has been conducted at industrial laboratories such as AT&T Bell Laboratories, Bolt Beranek & Newman, IBM Watson Laboratories, and the XEROX Palo Alto Research Center. As a result of this research, we are now in a position to address complex real-world problems. The concepts, models, and computational tools are available.

Considerable information and data must be collected, sorted, managed, and used. Broadly incorporating real time information requirements and displaying data and information, both new and stored, for the crew is a major challenge. Provision must be made for the design of other items, such as tools and equipment, to perform human and human-assisted tasks in micro-g and partial-g environments on planetary surfaces and in the spacecraft. Human interaction with automation is necessary to obtain overall mission reliability and productivity for the crew members who will explore and live on these surfaces. Methods to effectively use robotic and intelligent systems must be delineated for achieving the maximum synergy of the capabilities and limitations of each. A strong case must be developed to show that the crew can effectively use robotic assistants, teleoperators, and virtual work stations to accomplish these missions.

1.5 PROGRAM GOALS AND OBJECTIVES

1.5.1 Near Term Goals

The major goal of this Project is to provide the technology which will enable safe and productive human performance throughout and after long duration space flights and planetary/lunar missions. It will be necessary to thoroughly understand the expected requirements of the missions and how these will affect the technologies which support human performance. Within this goal are three major sub-goals:

1. Human Performance Models, Data and Tools - provide the basic understanding of human's activities in the physical, mental, and perceptual domains and to identify important lessons learned about human activities from prior space and lunar missions.

2. Crew Support and Enhancement - address the development of technology and its applications for the evaluation of the crew's living and working activities in the spacecraft and planetary/lunar habitat.

3. Human-Automation-Robotic Systems - determine the means by which humans and automated or semi-autonomous systems can effectively work together.

During the final phases of the program (1993-1998), validated human performance models, detailed mission requirements analyses, and innovative technologies for enhancing human perceptual and cognitive capabilities will converge to provide detailed guidelines for crew support systems and for human-capability enhancement systems. Special emphasis will be placed on human-machine systems design, prototyping, and evaluation methods; on information systems for supporting exploration, discovery, and the management of large-scale scientific databases; and on tools for flexible work-management in H-A-R systems.

1.6 TECHNICAL APPROACH

The three major sub-goals as defined in the previous section (1.5) was used as the bases for the development of the program plan using a Work Breakdown Structure (WBS) format (Section 2). In each of the WBS elements the existing state-of-the-art will be evaluated, new data collected (as needed), laboratory tests conducted, and new technologies and proof of principles demonstrated. The technical insights and technology base provided by the R&T program in OAST and the results of studies performed by other NASA groups will be used as the foundation for this Project.

2.0 PROGRAM DESCRIPTION

This Section of the Project Plan will describe the technical and management strategies and concepts which will be implemented during the 5 years of the Pathfinder Program.

2.1 WORK BREAKDOWN STRUCTURE

The Work Breakdown Structure is illustrated in Figure 2.1-1,(p.6A). It is divided into three sections, shown under the top-level box, Space Human Factors:Human Performance Project. The number in the lower left corner of each box are the assigned FY1989 priorities relative to the other WBS elements of the same level in the hierarchy. A detailed discussion of each is provided later in this Plan.

As shown in Figure 2.1-1, the purpose of Models, Data and Tools (WBS 1.1) is to provide the basic understanding of humans' activities in the physical (WBS 1.1.1), mental (WBS 1.1.2), and perceptual (WBS 1.1.3) domains and to identify important lessons learned about human activities from prior space and lunar exploration experiences (i.e., Apollo, Skylab and Shuttle missions) (WBS 1.1.4). From this information, human engineering tools (WBS 1.1.5) can be determined. The first four sub-elements under this element all aim to produce "Human Factors Design and Analysis Tools" (2.5.5). Rather than assuming that this will happen automatically, it is called out as a separate sub-element because it deserves special attention.

Crew Support (WBS 1.2), shown in Figure 2.1-1, addresses the development of technology and its applications for evaluation of the crew's living and working activities in the spacecraft and planetary/lunar habitat. It includes such critical

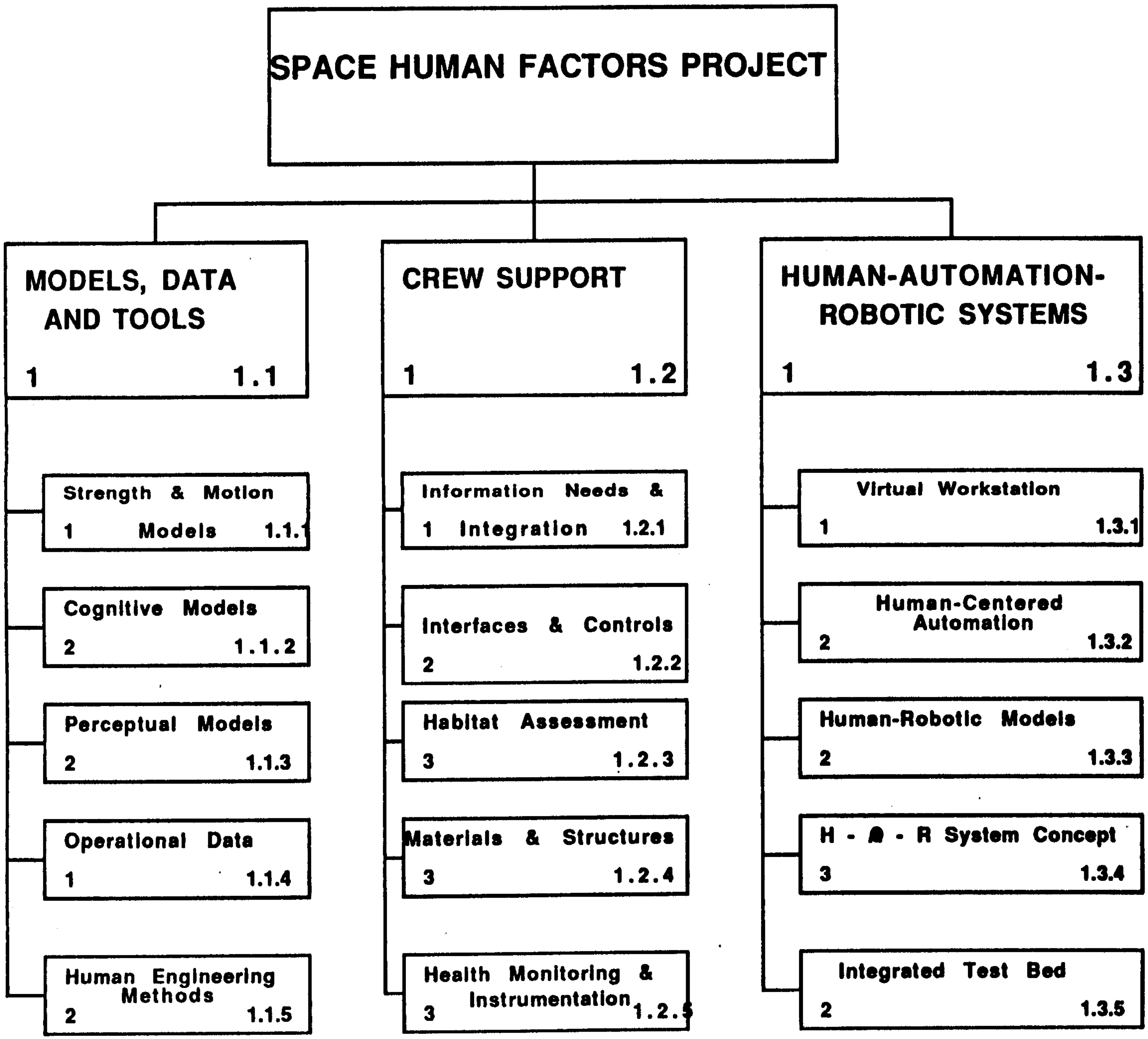
SPACE HUMAN FACTORS PROJECT
MODELS, DATA AND TOOLS
1 1.1
CREW SUPPORT
1 1.2
HUMAN-AUTOMATION-ROBOTIC SYSTEMS
1 1.3
Strength & Motion Models
1 1.1.
Cognitive Models
2 1.1.2
Perceptual Models
2 1.1.3
Operational Data
1 1.1.4
Human Engineering Methods
2 1.1.5
Information Needs & Integration
1 1.2.1
Interfaces & Controls
2 1.2.2
Habitat Assessment
3 1.2.3
Materials & Structures
3 1.2.4
Health Monitoring & Instrumentation
3 1.2.
Virtual Workstation
1 1.3.1
Human-Centered Automation
2 1.3.2
Human-Robotic Models
2 1.3.3
H - - R System Concept
3 1.3.4
Integrated Test Bed
2 1.3.5

FIGURE 2.2-1

tasks as anthropometry, communications, on-board training, maintainability, activity planning and scheduling, information management, safety, and workstations.

The man-machine interfaces will be studied under Interfaces and Control (WBS 1.2.1). Inputs to this task are a priority item for FY 1989 under the task entitled, Information Needs and Integration (WBS 1.2.2). For example, the Space Station analysis under the direction of Johnson Space Center, "Space Station Human Productivity Study", Lockheed Missiles and Space Company, Inc., 1985, identified man-tended systems, equipment, and issues for Space Station. These are listed in Table 2.1-1 to illustrate the scope of Crew Support tasks.

Man-Tended Interfaces

General layout	Traffic flow
Decor	Materials
Anthropometry	Modularity
Windows/Remote viewing	Stowage/Storage
Internal environment	External environment
Induced environment	Area lighting
Noise and vibration	Crew safety
Waste/trash management	Supply support
Mobility aids	Restraint systems
Communications	Quality assurance
On-board training	Maintenance
Maintainability	Support equipment
Activity planning & scheduling	Man-machine roles
Autonomy	Workstations
Data management	

Table 2.1-1

For each one of the items in Table 2.1-1, a further topical breakdown can be performed. For example: Windows/Remote viewing decomposes into - a) viewing requirements, b) window optical characteristics, c) window configuration, d) window access, e) window location, f) window maintenance/ protection, and g) indirect viewing options.

Habitat Assessment (WBS 1.2.3) will focus on crew requirements for planetary habitat(s) and lunar habitat(s). As of this date, preliminary mission scenarios produced by Code Z strongly suggest that different habitats will be required for living and working on the moon, on Phobos, and on the Martian surface.

Materials and Structures (WBS 1.2.4) addresses the crew contribution to working with different materials and structures on the planetary/lunar surfaces. For example, the human contribution to the construction or erection of a habitat or emergency shelter would be studied.

Health Monitoring and Instrumentation (WBS 1.2.5) will respond to biomedical requirements being studied as part of the Humans-in-Space Element managed by Code E, Life Sciences Division. For example, under the previously referenced Lockheed report, such issues as seen in Table 2.1-2 were identified and could be included within this task.

Health Maintenance Issues

Personal hygiene -
a) body waste management
b) whole-body cleaning
c) partial-body cleaning
d) body grooming

Health maintenance -
a) physiological conditioning/countermeasures,
b) physiological status monitoring
c) disease prevention,
d) accident prevention,
e) stress management

Waste/Trash Management -
a) trash generation
b) trash collection
c) trash sorting
d) microbial stabilization
e) waste/trash transfer
f) volume reduction
g) waste/trash disposal

Table 2.1-2

Human-Automation-Robotic Systems,(H-A-R), (WBS 1.3), is one of the highest priority topics for research, as shown on Figure 2.1.-1. Telerobotic Operator Interface (WBS 1.3.1) is a top priority effort in FY 1989 and builds on the R&T effort called "Virtual Interactive Environment Workstation (VIEWS)". Its thrust is to develop a technology in human-computer interfaces which involve spatial information transfer and human- information interaction. Planetary/lunar data will be utilized via terrain-imaging methods so that astronauts can examine in gross or fine detail the effects of terrain on such tasks as surface exploration. The result of this effort will provide a technology to visualize planetary data as virtual images of the terrain and to explore that data as one would explore the surface of a land mass from a perspective as low as nap-of-the-earth flying or as high as Landsat images. Human factors topics of interest include resolution, 2-D and 3-D cues, motion relative to the human observer, and interaction with terrain data bases.

Intelligent Systems Interface, (WBS 1.3.2), addresses the relationship and interaction of the crew with automated systems for exploration, transit to and from the planetary/lunar surface, in the habitat and in extravehicular or independent vehicular activities.

An important product from this effort is a set of guidelines for effectively integrating human and automated functions, such as proximity operations, navigation, logistics inventory, and diagnostic and maintenance aids.

H-A-R Information and Control Flow, (WBS 1.3.3), will be directed toward development of methods for interfacing with and properly using robotic assistants. Significant analyses and insights from Space Station and from the R&T base will service to focus this task. Table 2.1-3 lists types of applications of robotic technology to the human exploration activities.

Robotic Technology Applications

Servicing	Docking and Berthing
Inspection and Maintenance	Assembly and Construction
Deployment and Retrieval	Materials Handling
Installation and Removal	Search and Rescue
Scheduling and Replanning	Payload Servicing
Proximity Operations	Logistics

Table 2.1-3

H-A-R Systems Systems Measurement and Validation, (WBS 1.3.4), will focus on design and evaluation methods which are useful in the design of such systems. The technology to be developed will include modeling frameworks that interface with the engineering environment, will identify rapid prototyping methods, will perform function allocation analysis of specific combinations of crew,automated systems and robotic assistants, and will provide workload/ performance prediction and assessment techniques. This effort will integrate the results of WBS 1.3.1-1.33.

The H-A-R Systems Test Bed, (WBS 1.3.5), addresses the verification and validation of the H-A-R concept within a test and evaluation environment which is economical and flexible.

2.2 MANAGEMENT PLAN

2.2.1 Management Structure

The Space Human Factors Project is managed by the Program Manager for Human Factors, Division of Information Sciences and Human Factors, Code RC. The Program Manager is responsible for establishing a sound technical program, schedule and budget, and for reporting progress. Responsibility for Center assignments, approval of project plans, and funding allocation will remain at Code RC. Quarterly project reports will be submitted to OAST tracking progress against Level 1 schedules and identifying any problems, issues or significant accomplishments. Ames Research Center, Johnson Space Center, and Langley Research Center are designated to implement specific tasks.

Program advice and coordination is provided by the Space Human Factors Inter-Center Working Group, which is composed of representatives from the NASA Centers (see Section 2.2.2).

A lead manager for tasks at each Center will be identified by the Center's management. The selected individual is responsible for the detailed planning, overall management, and actual implementation of the project tasks. Technical tasks may be accomplished using a mixture of NASA in-house efforts, contracts, grants, and cooperative agreements. Emphasis will be placed on broadening the base of Space Human Factors technology within NASA, industry, and universities in order to provide a more competitive environment for future Pathfinder activities.

2.2.2 Program Coordination

The coordination of activities within the Space Human Factors Element is performed by the Program Manager, via the Inter-Center Working Group. The coordination of activities between this Element and other Elements in the Pathfinder program is performed by the Program Manager. The Program Manager for this Project is also the Program Manager for EVA/Suit and will arrange mutually beneficial exchanges of information between the two Projects as part of his Program Manager functions. A Humans-in-Space Program Integrator, a staff member in the Director for Space, Code RS, is the locus for internal coordination. Figure 2.2.1 illustrates this trail of coordination

The coordination of activities between this Element and other Elements in the Pathfinder program is performed directly by the Program Manager in coordination with the Humans-in-Space Program Integrator, Code RS. This Project will require close coordination with the Office of Exploration, Code Z, which is expected to provide mission scenarios to the Project. These can provide a starting point for development of technologies. Further,the Office of Space Station, Code S, will be a rich resource of information about human performance during the five years of this Project.

2.2.3 Program Planning

A Level 1 schedule of major milestones for the Space Human Factors Element is given in Figure 2.2-2. This Five Year Project schedule will be reviewed each year to insure it matches the current budget resources on the one hand and is sensitive to prior progress. Every attempt will be made to clarify the expected differences between progress, which has been planned on the basis of a full, 100% funding capability, and the actual progress which results from the fiscal year resources. The annual review will allow redirection of the technical focus as mandated by national plans for space exploration, unexpected technological developments, or re-prioritization. This review will be conducted by the Element Program Manager with representatives of each of the participating Centers. Changes to this Project Plan , if any, will be documented to provide an accurate Plan for each fiscal year.

Figure 2.2.-3 provides a top-level schedule for the program during the course of a ten-year cycle.

2.2.4 Program Reporting

Reports

Quarterly progress reports of major tasks in the Work Breakdown Structure will be prepared by each participating task leader at the Centers and submitted to the Project Manager. The Project Manager will collate these and submit them to OAST management. Each report will contain the information shown in Figure 2.2.-4 and will employ the format therein.

An annual progress report will be prepared by the Project Manager with the

SPACE HUMAN FACTORS

PROGRAM

MANAGEMENT STRUCTURE

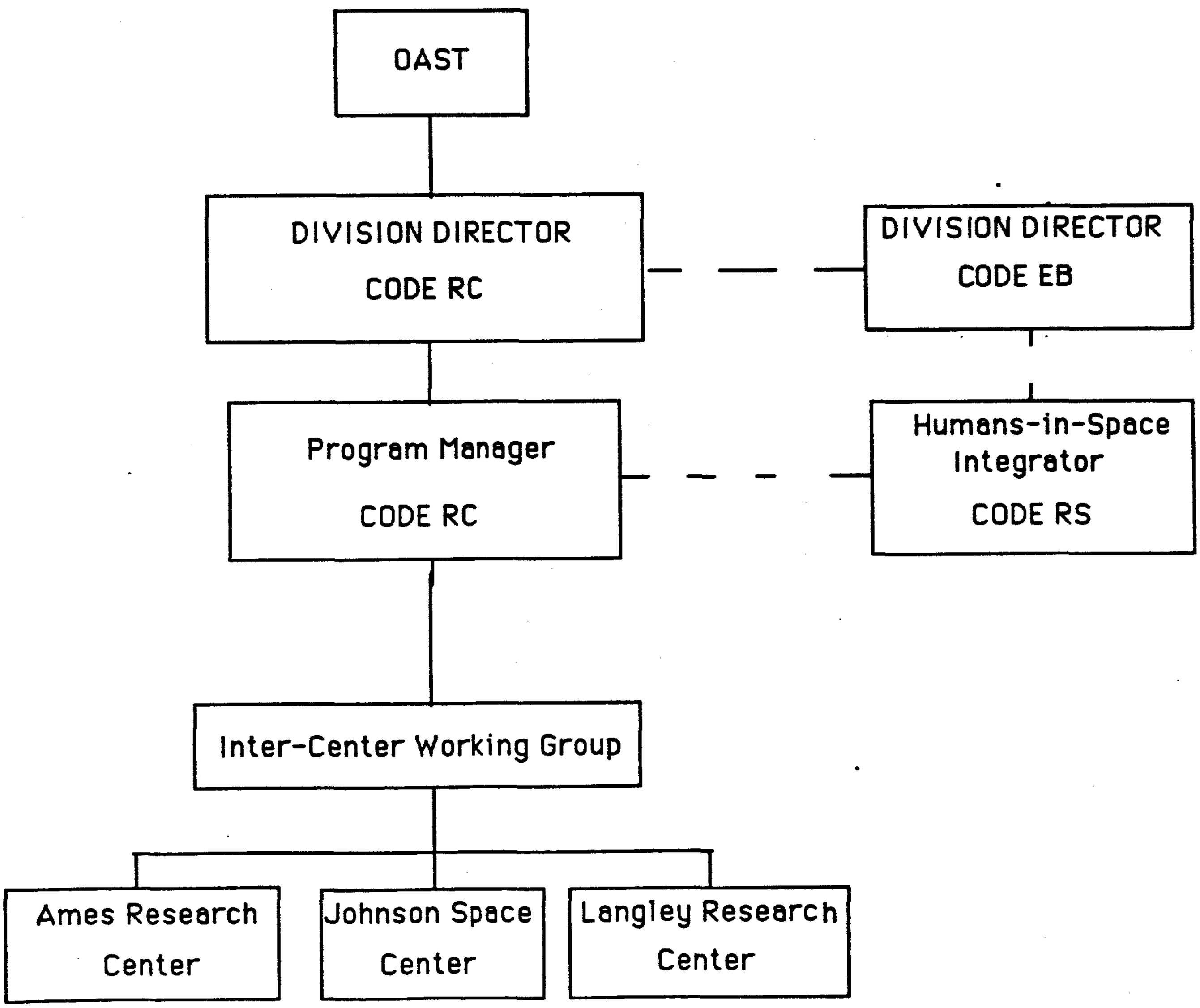

FIGURE 2.2-2

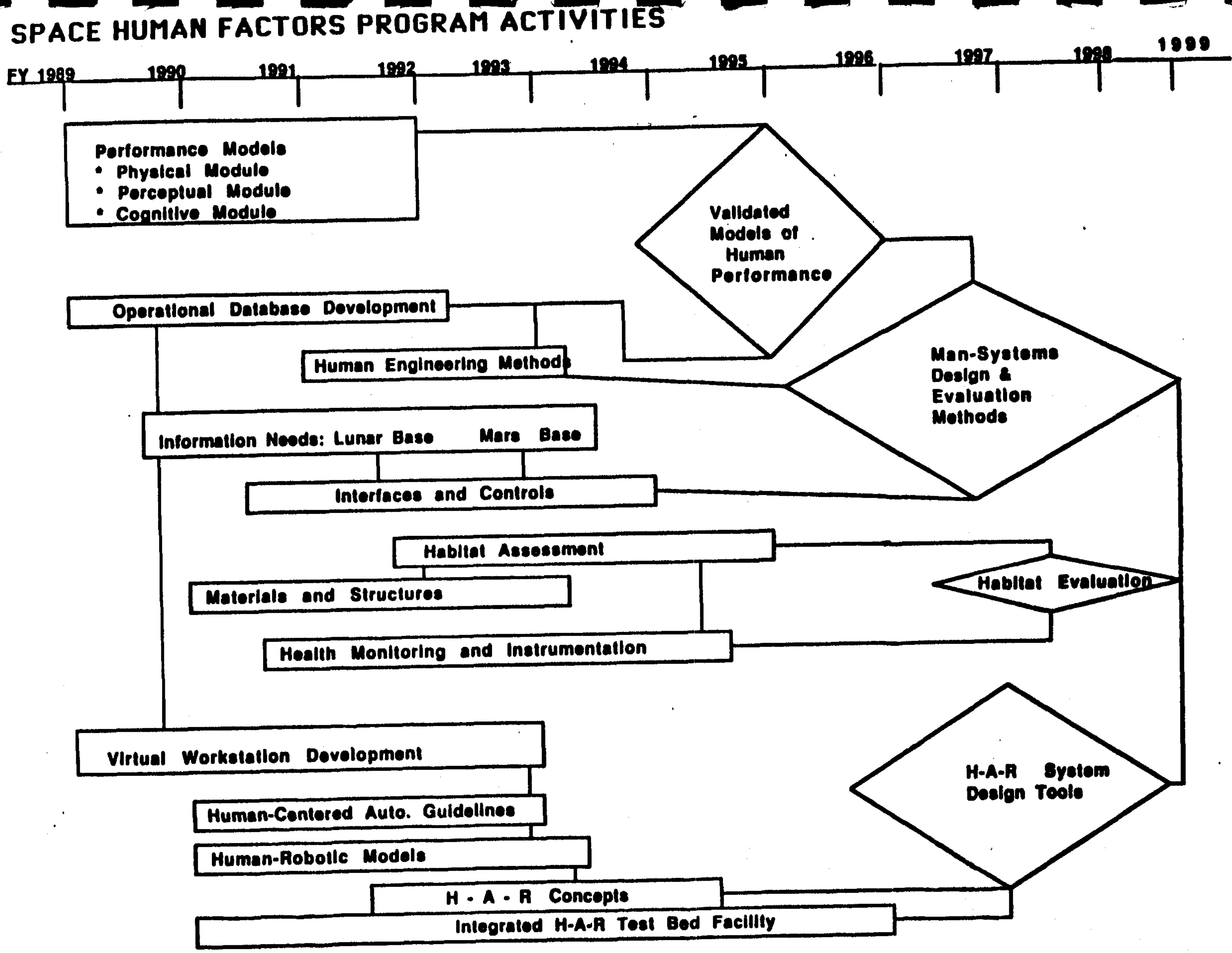
SPACE HUMAN FACTORS PROGRAM ACTIVITIES
FY 1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
Performance Models
• Physical Module
• Perceptual Module
• Cognitive Module
Validated Models of Human Performance
Operational Database Development
Human Engineering Methods
Man-Systems Design & Evaluation Methods
Information Needs: Lunar Base Mars Base
Interfaces and Controls
Habitat Assessment
Materials and Structures
Habitat Evaluation
Health Monitoring and Instrumentation
Virtual Workstation Development
H-A-R System Design Tools
Human-Centered Auto. Guidelines
Human-Robotic Models
H - A - R Concepts
Integrated H-A-R Test Bed Facility

FIGURE 2.2-3

assistance of the task leaders at the Centers. It will summarize the progress, accomplishments and major activities for the preceding year and identify the important tasks and milestones for the subsequent year. This information will be documented in the updated Project Plan, as an Appendix.

Project Reviews

Project reviews are the tools which the Project Manager/Program Manager will use to implement the Work Breakdown Structure concept to manage the project. Reviews allow the opportunity to keep the project on schedule and within budget guidelines, provide a forum for free interchange among the task leaders at each Center in order to share data, to identify promising technology and to avoid duplication of effort. A Project review is held semi-annually.

Each task manager will report on the WBS elements which have an ongoing effort at their Center. This report will include items covered by the Quarterly Progress Report. Successful milestones will be presented, problems addressed and proposed changes to the Project Plan will be made. Administrative issues and suggested corrective actions for them will be provided, as needed. Members from the NASA STD 3000 Manned Systems Integration Standards (MSIS) working group will be invited, annually, so that the results of the research and technology development can be incorporated into the NASA STD 3000.

2.3 RESOURCES

2.3.1 Five-Year Funding

Fiscal resources to conduct the Project through FY 1993 are shown in Table 2.3.1-1. Both the funds for FY 1989, which have been approved by the Administration and passed by the Congress as part of the Budget, as well as the planned amounts for FY 1990-1993 are given according to the top level WBS.

These funds will be distributed to the Centers by OAST. It should be noted that tasks in the WBS having a priority of 1 must be fully funded in the fiscal year in which the Project Plan is prepared, whereas priority 2 tasks may be funded in whole or in part (see Figure 2.1-1) Priority 3 tasks are outyear tasks.

Staff resources required within each Center to support this Project are provided in Table 2.3.1-2.

Financial Resource Allocation
($K)

WBS Element	FY1989	1990	1991	1992	1993	1994
1.1 Models, Data & Tools	210	400	1,600	1,300	900	800
1.2 Crew Support	100	500	1,300	2,500	3,100	4,200
1.3 H - A - R Systems	361	600	1,100	3,200	4,000	5,000
Center facilities & Reserve	156	(tbd)	(tbd)	(tbd)	(tbd)	(tbd)
TOTAL FUNDING	827	1,500	4,000	7,000	8,000	10,000

Table 2.3.1-1

Center Staff Requirements

Center	Fiscal Year	Total Staff Required	Referenced to FY1989
ARC	1989	7.0	0
	1990	40.0	33.5
	1991	62.5	55.5
	1992	85.5	78.5
	1993	86.0	79.0
	1994	90.5	83.5
LaRC	1989	0.5	0
	1990	1.0	0.5
	1991	3.0	2.5
	1992	5.0	4.5
	1993	5.5	5.0
	1994	6.0	5.5
JSC	1989	1.0	0
	1990	1.5	.5
	1991	1.5	.5
	1992	2.0	1.0
	1993	2.0	1.0

Table 2.3.1-2

3.0 Element Description

Mission requirements and objectives for lunar and planetary exploration will be used to identify human performance needs and to compare such needs with known human capabilities and limitations. Assumptions about human performance requirements and human tasks will be developed to supplement formal mission studies. Efforts will be directed to identifying and using the experience gained from U.S. flights of Apollo, Skylab, and Shuttle and Soviet space missions as they relate to these new missions. Prior and current Space Station studies will be reviewed and applicable insights and information will be extracted for this Project. The Space Human Factors program will focus on the development of techniques for modeling human physical and cognitive (i.e., decision making, judgmental activities, perceptual functions) activities.

These computational models of human performance will be validated against data collected in moderate fidelity simulations of mission tasks. This effort will demonstrate the scope, reliability and usefulness of the models and underlying data.

3.1 MODELS, DATA AND TOOLS

The ability of astronauts to work safety and effectively in transit to and from lunar and planetary exploration sites, under zero and partial-g conditions, for long periods of time must be predicted validly. This Element is intended to provide the basic understanding and database about human's activities in the physical, mental, and perceptual domains. There exists a prior record of astronauts' successes in similar environments, via Apollo missions to the Earth's moon, data from Skylab missions and numerous Shuttle missions. Effort will be focused in this Element to collect, categorize and apply this operational experience to the expected missions in Pathfinder. Operational experience, coupled with data and models about human physical, mental, and perceptual capabilities, will provide a baseline of requirements for the Project.

The primary objective of this sub-element is to develop physical performance models of motion, anthropometric constraints and limitation, and human strength. These models will be used in conjunction with perceptual and cognitive models to provide a comprehensive framework for understanding past mission data and for predicting performance in Pathfinder mission environments. These models will also be used to aid systems designers and to evaluate systems design from a human factors perspective.

3.1.1 Systems Analysis

An understanding of the entire use of humans in lunar/planetary exploratory activities will be developed.

3.1.1.1 Objectives

One objective is to identify the crew requirements for safe, productive life and work in space. Their capabilities and limitations for dealing with the environment must be known, including such diverse factors as physical strength and information acquisition and processing. Besides the strictly work related capabilities, the requirements for a satisfactory lifestyle within the constraints of the mission must be identified and met. This may include studies of how much free time is required, what leisure activities should be provided, how much privacy vs. interaction is desirable. It will also include such necessities of life as health care and maintenance requirements, food and clothing requirements beyond those simply necessary for survival, and communications with the "outside world."

3.1.1.2 Technical Approach

Resource management in long-duration missions requires good planning, both in advance and in real time for meeting day-to-day needs. With a highly automated, extremely complex spacecraft or facility, techniques for assessing status and managing the vast amounts of information about the environment are of key importance. There will also be extensive scientific information to manage as experiments are conducted, and both operational and research-oriented skills to be acquired or maintained.

To plan successful missions and build effective craft and equipment requires a thorough knowledge of the requirements of humans in space. Since this is beyond the everyday experience, or even the general engineering training, of most designers, the data must be made available by NASA.

Ground crew support for long term missions will be of major importance. The ground crew functions can be automated to varying degrees, but certainly communications and monitoring will need to be maintained. The nature of the teamwork between ground crew and astronauts will help to determine the success and productivity of the mission. An objective to strive for is well-structured teamwork between the crews, and determination of how much autonomy the astronauts in space will have.

3.1.1.3 Description

The principal source of information to perform the system Analysis are plans for Pathfinder which lay out the basis for the use of humans in space and mission studies, being performed by Code Z. This set of information will be reviewed to define the underlying requirements for the roles of humans. Assistance from Code Z will be required. Therefore, Schedule, Milestones, and Resources are expected to be derived from Code Z plans (not available as of the date of completion of this Plan).

3.1.2 Strength and Motion Models

Provide the basic understanding of human activities, requirements and capabilities in the physical domains for Pathfinder missions.

3.1.2.1 Objectives

The primary objective of this sub-element is to develop physical performance models of motion, anthropometric constraints and limitations, and human strength. The models will be used in or are applicable to all the other elements of the Human performance plan for the Pathfinder program. The effort will be broken into two primary parts:

- The collection of physical and dynamic data on human capabilities in shirtsleeve and space suits in zero, partial, and one-g.
- The development of computerized models of strength and motion in zero, partial, and one-g such that time dependent variations may be incorporated.

3.1.2.2 Technical Approach

A review of existing data bases and data collection methods will be conducted to determine which existing data bases are applicable and what new data or new methods of data collection are required. Additional data requirements will be identified and will include the effects of zero and partial-g on the 3- dimensional work regime required by persons in shirtsleeve and space suited conditions. The data base developed will include static and dynamic data. Types of data will include anthropometric, strength, reach, force application, and the effect of space suits on each of the parameters. The models will also take into account the effect of articulated motions for biomechanic tasks. The models will be incorporated with full man-modeling and space craft modeling. The models will be validated. and used to support other parts of the Pathfinder Human Performance elements. As data requirements are established they will be incorporated in NASA STD 3000, Man-Systems Integration Standards (MSIS).

3.1.2.3 Description

Long-duration mission will require a degree of autonomy from ground-based control. Consequently, the mission planners will need the tools to be able to analyze and understand man's physical capabilities in the various situations and environments that the astronauts will be required to work. The data bases resulting from this effort will be incorporated in the modeling capability being developed. The models will provide a needed basic human physical performance capability tool.

The Johnson Space Center computer man modeling and mission analysis engineering tools PLAID and TEMPUS are at the state of the art. These programs permit high fidelity modeling of engineered environments and the people in them. They have dynamic motion capabilities to permit examining the envelopes of linked structures such as the Remote Manipulator System or a human body moving in a specified environment. Animation capabilities are also present, with the ability to specify any problems, or improper placing of controls. A strength model is currently under development which can predict the motions of a human body (or simpler object) given applied forces which may be external or self-generated.

The Laser-based Anthropometric Mapping System (LAMS) and the Strength and Motion Modeling projects are providing data and models to the Johnson Space Center CAE system PLAID/TEMPUS. In particular, physical data is collected in 1-g and 0-g to describe the human body and its capabilities.

3.1.2.4 Schedule

FY89 Data collection, analysis and documentation of existing models. Definition of additional data needed by models.

FY90 WETF data collection. Specifications of modifications needed to current model for partial-g and for strength limitations.

FY91 KC-135 data collection. Model modification to test for joint strength limits as well as range of motion, and to incorporate partial-g effects. Flight data collection.

FY92 Continue data collection. Model enhancement to include spacesuit effects.

FY93 Validate model against flight data. Document installation and operational procedures.

FY 94 Distribute model to potential users. Maintain data base and minor modifications for easier use.

3.1.2.5 Milestones

FY89 Documentation of current model. Initial data base.

FY90 Specifications of multi-purpose model. Extend data base.

FY91 Human model with joint strength. Extended data base. First in-flight data collection.

FY92 Model of spacesuit effects. Data base of space suit effects

FY93 Flight data collection of strength data. Program documentation.

FY94 Disseminate model.

3.1.2.6 Resource Allocation

	FY89	FY90	FY91	FY92	FY93	FY 94
COST $K	70	125	500	500	500	500

3.1.3 Cognitive Models

This sub-Element involves the analysis and modeling of human cognitive processes, modeling of the mission-oriented tasks, and application of these models in the determination of operator capabilities and systems designs.

3.1.3.1 Objectives

The objective of this sub-Element is to provide computational models of the human operator which is an important tool in guiding human-system design for Pathfinder. The goal is to produce a set of models that span a range of human cognitive functions and provide methods for decomposing complex tasks into their cognitive requirements. As a result, human factors engineers and planners or analysts will be able to make important precise, quantitative statements about the impact of system designs on human performance.

3.1.3.2 Technical Approach

A Resource Constraint Model will be developed in house that specifies the architecture of the human information processing system. This model will be coupled with a method for analyzing complex NASA space-related tasks into their cognitive resource demands. Throughput and demands are then calculated. Models will be augmented by graphical representations of their functioning so that designers can visualize and predict the impact of design options on information and control flow.

A cognitive task analysis effort will be undertaken to specify the processing requirements of representative Pathfinder exploration missions and scenarios. The tasks in this sub-element will be performed using a combination of NASA in-house expertise with the appropriate support and grants with the institutions.

3.1.3.3 Description

Resource Constraint Modeling: A computational model of the architecture of the human information processing system will be developed, based on existing and/or promising models. A system will be developed which will allow researchers to test and validate proposed models. The validated models will provide the basis for a design support system. The graphical representations of the model will suggest modifications to designs which would make better use of the human's cognitive processing resources and capabilities.

Cognitive Task Analysis: Research will be conducted to find methods to represent a variety of important operator tasks at a cognitive resource level. This will enable the generalization of empirical results across superficially different task domains. The effort will examine astronauts' tasks and jobs in the proposed missions and scenarios and several will be chosen for both their importance and model suitability. The results of this research will provide to the analysis group the required cognitive input parameters. The tasks in this sub-element will be performed using a combination of NASA in-house expertise with the appropriate support and grants with the institutions.

Decision making: Decision making (including models of knowledge representation and problem solving) models in existence or under development will be selected and applied to the above activities. A combination of university grants and visiting scientist program efforts will be used to perform this sub-task.

3.1.3.4 Schedule

FY90: General human-system modeling framework chosen; mathematical basis for qualitative cognitive process modeling selected. Identify tasks and scenarios for task analysis.

FY91: Definition of task analysis/cognitive modeling interface; initial task-analysis and cognitive modeling framework defined.

FY92: Complete task analysis and cognitive modeling framework. Develop guidelines for application of models and task analysis to develop interface design.

FY93: Cognitive models completed for 3 tasks; task analysis and simulation for 3 tasks completed. Define demonstrations of the user/system interface and begin demonstrations with evaluations by astronauts, operators, and system developers.

FY94: Validation experiments completed for 3 tasks. Complete and evaluate demonstration prototype. Document procedures and disseminate to potential users.

3.1.3.5 Milestones

FY 90: Literature review on existing models

FY91: Technical report on task analysis/cognitive model interface and framework

FY92: Documentation of task analysis and cognitive modeling framework and related software methods and tools

FY93: Documentation for 3 tasks and completed software

FY94: Final report of experiments and studies and software distributed

3.1.3.6 Resource Allocation

	FY89	FY90	FY91	FY92	FY93	FY94
Cost $K	0	600	800	800	800	800

3.1.4 Perceptual Models

Human-centered design of crew workstations can ensure that information is presented clearly and that crew intentions are effectively communicated to the system. An astronaut's ability to respond to a multitude of mission demands depends upon his/her state of vigilance, mental status and workload, other tasks, and the degree to which the response appropriate action is understood and defined,. Models of perceptual performance can predict operator performance, and thus can be used to choose between alternative crewstation design options. Perceptual models also can be used to ensure that crew response can occur in a timely and appropriate fashion.

3.1.4.1 Objectives

The objective of this sub-element is to integrate models of human perception which are likely to be critical to the performance of crew actions at workstations. Specifically, it is planned to use existing perceptual models to understand how an astronaut will use visual cues from displays or the natural environment to perform his/her tasks. Examples of such tasks include landing site selection, planetary landings, orbital fly-by exploration missions, base site preparation, and vehicle docking. This sub-element aims to produce such tools, and to determine where more advanced tools may require additional basic research.

3.1.3.2 Technical Approach

Models of human perception will be integrated to enable the implementation of a computer-aided design system for crew-system interfaces. Appropriate individual perceptual models of vision and audition will be put into computational form. Complex human behaviors, such as vigilance, seeing, hearing, or planning, will be approximated in such models. A perception-based design tool will be developed with special emphasis given to three-dimensional displays and controls. Using this perception-based design tool, the effectiveness of various crewstation designs will be evaluated with different mission scenarios. Human performance data will be obtained at a very low cost, as compared to high-fidelity simulation methods. The most effective crewstation concepts, as determined by the perception-based design tool, can be tested and evaluated.

3.1.4.3 Description

Improved methods for visual display and manipulation will be investigated for use in the perception-based design system (PBDS). Among the candidate display methods to be studied are: dual-display stereo, time-multiplexed single display stereo, holographic stereo, volumetric sweep stereo, or nonoscopic motion parallax. A three-dimensional 'mouse' will be developed to permit rapid control response and orientation in the 3D work space.

A systematic survey of the existing choices for display hardware, computer hosts for graphics engines, and graphic software will be conducted. This survey will focus on the trade-offs that are inherent in the various choices and combinations for hardware and software. A 3D system will be procured and developed. The hypothesis will be evaluated that a fully 3D system supports higher productivity and simplifies the operation of CAD systems. The various mouse types will be evaluated. The 3D system will be integrated into a general purpose crewstation design and evaluation system.

3.1.3.5 Milestones

FY90: Compute field of view for each eye. Model symbol visibility and confusion in the luminance range of 1 to 300 foot candles for foveally fixated images. Survey the existing choices for display hardware, computer hosts for graphics engines, and graphic software.

FY91: Model the effects of convergence, accommodation and their impact on depth of field. Extend the luminance range in which visibility and confusion models are validated. Procure a 3D graphics editing system and develop it.

FY92: Model obstacles in the field such as helmet, surfaces, nose, etc. Add color and motion to the modeling of symbol confusion. Evaluate the hypothesis that a fully 3D system supports higher productivity and simplifies the operation of PBDS systems

FY93: Model the cyclopean image of perception. Add the effects of retinal location to visibility/confusion models. Integrate the 3D graphics editing system into a general purpose crewstation design/evaluation system

3.1.3.6 Schedule

FY90: Field-of-view, symbol visibility, and confusion models in the luminance range of 1 to 300 foot-candles for foveally fixated, monocular image. Portable software version of the model will be available to other NASA Centers.

FY91: Model for the effects of convergence, accommodation and their impact on depth of field. Extended luminance-range models for symbol visibility and confusion. Initial 3D graphic editing system configuration developed.

FY92: Model for obstacles in the visual field available. Color and motion added to the modeling of symbol confusion.

FY93: Model for the cyclopean image of perception. Retinal location added to visibility/confusion models. Complete general purpose crewstation design system.

3.1.3.7 Resource Allocation

	FY89	FY 90	FY91	FY92	FY93	FY94
$K	0	100	200	300	300	500

3.1.5 Operational Databases

Identify important lessons learned about human activities from prior space and lunar exploration experiences in order to develop an operational database.

3.1.5.1 Objectives

The general purpose of the element is the development of operational data and lessons learned that take into account human performance as revealed in actual space flight and operations. This sub-element will focus on experience gained in lunar exploration, which is the closest analog to planetary exploration. The astronaut and operations personnel experiences will be analyzed and integrated into a data base with other space operations requirements and data, such as the information in NASA STD 3000, Man-Systems Integration Standards, and the biomechanics data base.

3.1.5.2 Technical Approach

Data on human factors in operational experiences will be collected from original sources wherever possible. Lunar astronauts will be interviewed and their replies analyzed for generalization guidelines. Videotapes and transcripts will be studied. Data from Skylab astronauts will be similarly collected as representative of the longest duration U.S. space flights. This information will be integrated with that collected from Shuttle flights under the Base R&T RTOP. A unified data base will be designed to integrate this information with other human factors data bases such as the Man-Systems Integration Standard, the biomechanical data bases, and others which have been generated. An integrating front end will be constructed to allow the user to access all these sources as if they were one database instead of having to learn to operate several different systems. The data in the database will be used to analyze requirements for simulators, for testing, and training in simulated partial g. Such simulators will be designed and constructed in Element 1.2.2, Interfaces and Controls.

3.1.5.3 Description

Previously collected data about the performance of Apollo astronauts and operational planning personnel will be reviewed, as will information from the Systems Analysis sub-Element. A database will be developed and distributed for use in spacecraft and habitat design, mission planning, and related Pathfinder elements. These databases and "lessons learned" will be translated into specific guidelines for the human factors design and evaluation of manned stations, tools, and subsystems.

3.1.5.4 Schedule

FY89: Identify sources and personnel to be used, develop questionnaires and taxonomy for organizing information. Select a data base structure. Review literature and interview persons familiar with Apollo operations.

FY90: Continue interviews and data abstracted from films, tapes, recordings, and transcripts. Incorporate in data base. Develop approach for extracting guidelines and requirements form data entries.

FY91: Complete interviews and continue extracting data from written and film sources. Develop plans for simulating conditions in partial-g simulator to validate guidelines.

FY 92: Complete data base. Begin developing integrated Man-Systems data base to enable user access to all relevant data bases through same interface.

FY 93: Distribute data base. Complete integration of other human factors data bases, and document interface.

FY94: Distribute integrated data base and provide user training on interface. Develop plans for maintenance of data base under either Base R&T or program support.

3.1.5.5 Milestones

FY89: Taxonomy and list of sources developed.

FY90:Refine taxonomy and data in data base . Publish preliminary method for extracting requirements and guidelines.

FY91: Completed interviews entered in database..

FY92: First validation tests performed in partial-g simulation,

FY93: Design of integrated data base completed.

FY94: Data base published. Interface for multiple data base completed.

3.1.5.6 Resource Allocation

	FY89	FY90	FY91	FY92	FY93	FY94
Cost $K	65	100	500	250	200	200

3.1.6 Human Factors Design and Analysis Tools

Provide a mechanism for information transfer to users of human factors in order to foster the development of engineering tools. Reduce the difficulties associated with translating cognitive and perceptual models into tools which can be easily used during the conceptual design phase.

3.1.6.1 Objectives

The purpose of this effort is two fold: first, to provide to the NASA technical Centers and their supporting contractors and universities an opportunity annually to engage with the entire Space Human Factors Project and its principles. This annual meeting will be co-sponsored with the Life Sciences Division, OSSA, research for Humans-in-Space Thrust of Pathfinder. Not only will information be disseminated, but also the plans for the next year and the technical approaches will be reviewed and modified, as needed. Second, to determine and develop, if necessary, the new human engineering tools which may be needed for design of information displays, other human interfaces in space craft and habitats, in partial, and zero-g for both a shirtsleeve and space suited environments. The objective is to reduce the difficulties and costs associated with translating physical, cognitive and perceptual models into tools which can be easily used during the conceptual design phase. Human performance models will be treated as products and system designers as potential consumers of these products.

3.1.6.2 Technical Approach

First, yearly conferences will be conducted to bring together the personnel working in the relevant areas to allow the interchange of information and program planning. Examination of the results of prior sub-elements and products of research about operational experience and lessons learned, will be reviewed to determine if new human engineering methods are needed.

Second, obstacles to the use of human performance models by designers will be identified and analyzed to determine obstacles and identify remedial steps to increase their usefulness. Obstacles may include the perceived applicability, credibility, availability, interpretability, language, and usability of perceptual and cognitive models.

Third, guidelines will be developed for more effective communications between human performance modelers and system designers. Potential solutions will be formulated and evaluated.

3.1.6.3 Description

Existing data and models will be examined to determine whether new human engineering methods are required as a consequence of prior research results. Selection by designers among available information sources is heavily influenced by factors, such as how easily the information can be obtained and applied, internal policies of the organization, prior history of success in designing the product, or other elements. Frequently, the designer's own judgment is a major factor. Many times, the design is a product of numerous individual efforts, with no single person being responsible for the entire design.

A focused effort will be undertaken to reduce the difficulties associated with translating physical, cognitive and perceptual models into tools which can be easily understood, accessed, and used during the conceptual design phase.

3.1.6.4 Schedule

FY89 - 94: Organize workshops, select sites, select speakers, and invite participants from the research and user communities. Conduct annual workshops.

FY 90: Based on initial workshop results, identify designer's information sources. Identify representative and applicable strength, cognitive, and perceptual models.

FY 91: Develop "designer friendly " tools based on applicable models. Begin to evaluate tools for use by designers.

FY92: Report results at annual Workshop and revise tools as needed.

FY93: Report results at annual Workshop and revise tools as needed.

3.1.6.5 Milestones

FY 89-94: Annual Workshop report

FY 91: Prototype "designer friendly" tool documented.

3.1.6.6 Resource Allocation

	FY89	FY90	FY91	FY92	FY93	FY94
Cost $K	25	125	200	50	50	50

3.2 Crew Support

Multisensory systems for information integration in the spacecraft and in the lunar/planetary habitat will be used to develop an interactive information management system and to aid in operational planning and teleoperations. The interactive information management system will include advanced display and control technology. Test and demonstration of the emerging technologies will be performed to ensure their adequacy for meeting mission needs.

3.2.1 Information Needs and Integration

Identification of information needed for crew operations in transit and for exploration activities on lunar/planetary surfaces.

3.2.1.1 Objectives

The objective of this sub-element is to identify the information needs for the various activities expected to be required for long-duration space flights and planet surface operations planned for the Pathfinder program. An example of the type of needs to be identified are contained in Table 2.1-1 of this program plan, entitled "Man-Tended Interfaces". The list of interfaces was developed for the "Space Station Human Productivity Study" and identified man-tended systems, equipment, and issues for Space Station.

An important product from this effort is the guidelines for effectively integrating human and automated functions. New concepts and methods for measure of complex human-system interaction will be applied to allow the on-line reconfiguration of control and displays for spacecraft, robotics, and Lunar and Mars habitats. Information and experience gained in a related human factors research program, entitled "Aviation Safety/Automation", will be used in this sub-element. The results of this research will enhance crew productivity by providing an efficient, consistent interface between the crew and the spacecraft, the environment, tools, habitat, planetary surfaces, and other mission elements.

3.2.1.2 Technical Approach

Examine data unique to long duration missions and methods of collection. This effort includes review of existing knowledge of spacecraft, lunar surface operations, and partial-g studies with emphasis on human-system interfaces. Analyze Hardware, data storage, and transmission requirements. Perform task analysis and identify to the extent possible unique lunar/planetary factors (i.e., dust, atmosphere, lighting and visibility) on human-system interfaces and interactions. Perform partial-g simulations to select human-system interfaces and methods of interaction. Identify requirements for crew support and habitability in long duration missions including influence of new technology and interface requirements. Develop rules for human-systems interfaces and simulations of systems.

Data and information obtained in other research sub-Elements of this plan also will be utilized. Base R&T technologies, such as VIEWS-type capabilities or PLAID capabilities, will be applied to the maximum extent. Similarly, data and information from other human factors research areas, such as the Aviation Safety/Automation program, will be used.

3.2.1.3 Description

The human-system interface for large-scale integrated information systems will require a range of interaction modalities for operator intervention in the case of system degradation or conflicts in resource allocation. It is most important that the astronauts have flexibility to the greatest degree because they will be beyond the current ground-based support systems for many months. For example, efficient use of automated systems will depend on highly graphic, multi-dimensional status representations of the numerous subsystems in a format that can be easily monitored in parallel with other mission tasks. In the event of malfunction, the interfaces must be amenable to manual control. The degree to which expert system technology is mandatory will be investigated.

The crew support requirements for future missions, including the effects of new technology and interface requirements, will be analyzed. Guidelines for crew habitability for the long duration partial-g environments will be developed. Techniques and hardware for collecting performance data ,using non-intrusive measurement techniques, during the proposed missions will be specified.

Test and demonstration of the emerging technologies will be performed to ensure their adequacy for meeting specific mission requirements within the capabilities of the crew.

3.2.1.4 Schedule

FY89: Survey data and existing knowledge. Perform task analysis of surface operations. Identify planetary factors impacting display and control equipment, functions, and users. Establish an inter-disciplinary team with systems engineers to study the parameters the crew must understand and control. Review long duration mission data and collection methods.

FY90:Develop data collection and analysis system to standardize data collection efforts. Specify human-system functional interface requirements in detail with other Pathfinder Elements (i.e., Rover, Sample Collection, etc.). Review state-of-the-art on gloves, end effectors, display devices and input devices. Develop specification for a surface workstation(s). Determine best means for simulation of partial-g conditions. Develop conceptual designs of experiments for performance variables expected to change over long duration missions.

FY91: Continue above activities, as needed. Develop on-line human performance (non-intrusive) assessment methods. Develop interface design concepts for new spacecraft systems, as needed. Investigate hardware and design experiments compatible with long duration missions and the space station configurations.

FY92: Develop performance logging and display as a measurement capability. Conduct partial-g studies for interfaces and human-system interactions. Prepare and integrate data collection, storage, and retrieval techniques. Design spacecraft and habitat compatible equipment for experimental data collection. Test interface designs for new spacecraft systems.

FY93: Complete design guidelines for surface workstation and its displays and controls. Complete above studies and analyses, as needed.

FY94: Demonstrate the adaptive display technology and performance assessment methods for spacecraft and surface workstations. Test workstations, habitat design features and other equipment under partial-g conditions.

3.2.1.5 Milestones

FY89: Report on existing knowledge, equipment and display requirements for long duration missions . List of engineering disciplines expecting significant changes in user interfaces.

FY90: Report on state-of-the-art related equipment, hardware, and software. Specifications for surface workstation. Report on experimental designs and instrumentation for performance monitoring.

FY91: Report on partial-g tests. Description of interface design concepts.

FY92: Report on evaluation of input and output devices and studies of their potential applications. Experimental results on interface designs.

FY93: Guidelines for surface workstation. Evaluation of hardware for use in space craft .

FY94: Report of final partial-g simulations of crew-system interfaces and interactions. Refined analysis of crew interfaces for advanced spacecraft systems. Technology assessment and design guidelines for all displays and controls and other crew-system interfaces and interactions.

3.2.1.6 Resource Allocation

	FY89	FY90	FY91	FY92	FY93	FY94
Cost $K	65	600	1000	1200	1500	1300

3.2.2 Visualization for Planetary Exploration

The Visualization for Planetary Exploration project will provide mission planners, controllers, and crews with improved operational capability by providing a research and technology base for dramatically improved planetary visualization systems. This will be accomplished through a mission-oriented extension of successful research in spatial information transfer which has already produced: innovative perspective formats for the Cockpit Display of Traffic Information (CDTI) program; the Virtual Visual Environment Display (VIVED), an advanced helmet mounted display; the Virtual Interactive Environment Workstation (VIEWS), which adds Datagloves and 3D sound to VIVED; and the NAVIE display for conducting orbital rendezvous maneuvers.

3.2.2.1 Objectives

The objective of the Visualization for Planetary Exploration project is to enable rapid and effective understanding of the massive amounts of spatially correlated information vital to the success of planetary exploration missions. This will be accomplished by augmenting unique human visualization capabilities through the application of advanced automation. Effective presentation and manipulation of comprehensively integrated data, including both previously gathered and real-time data, will enable mission investigators to efficiently survey, select, and evaluate high-payoff, scientifically interesting regions, safe landing sites, and productive traversal paths. Using tools developed under this sub-element, mission personnel will be able to conduct rapid, widespread, and thorough analyses of potential resources, hazards, climatic and atmospheric changes, and identification of sites for more detailed future explorations.

3.2.2.2 Technical Approach

An interdisciplinary collaboration will involve human-system interface scientists, planetary mission and science experts, and computer scientists. U.S. and Soviet operational experience in lunar and planetary exploration will be reviewed, with an emphasis on the methods used to visualize spatial data. Current mission plans will be analyzed, focusing on the human factors of planetary surface information management and scientific visualization for manned and remote exploration. Increasingly mission-focused human factors evaluations will be conducted to gain interface design knowledge and to refine guidelines. Human exploratory behavior relevant to planetary exploration interfaces will be characterized. Methods, concepts, and strategies will be developed and validated for the management, display, and manipulation of planetary data. These will be based on mission operations and science requirements, human-computer interface principles, human exploratory behavior, and workstation capabilities.

The effectiveness of prototype systems will be evaluated by analyzing human performance in the context of simulated mission tasks and environments.

3.2.2.3 Description

Research and development will be focused on augmentation of human performance through the use of advanced visualization interfaces for planetary exploration. Initial activities will be to build an intercenter, interdisciplinary research team and to establish a mission-experienced advisory group. Researchers will work closely with appropriate mission experts to determine key operational challenges and opportunities. They will identify and interview exploration mission experts regarding human factors issues in the use of planetary surface data. The use of planetary imaging data in previous exploration missions will be investigated, and relevant operational experience and expert user requirements will be characterized. Research activities will include systems engineering, development, and implementation of prototype workstations for human-system interface studies and technology demonstrations. Existing planetary data will be used for user interface experiments. Researchers will characterize human exploratory behavior relevant to planetary exploration systems. They will document user strategies, interactive system modes, candidate formats, system implementation, and human-system interface design guidelines. Concepts will be validated in mission-oriented simulations in the ARC Human Interactive Systems Testbed.

3.2.2.4 Schedule

FY89 : Coordinate team and advisors. Initiate operational experience and requirements studies. Begin exploration interface research studies.

FY90: Complete initial operational experience and requirements studies. Initiate university studies. Continue development of prototype interfaces.

FY91: Integrate findings of the operational experience/requirements studies into the prototype user interface software. Obtain detailed critical analyses from experienced mission experts.

FY92: Develop mission-oriented prototype workstation and conduct studies to determine human-system interface guidelines.

FY93: Use prototype mission workstation to conduct simulations of key planetary mission operations with experienced personnel and apply critical observations to the interface design.

3.2.2.5 Milestones

FY89: Establish mission/science advisory group and intercenter, inter-disciplinary team. Establish exploration interface testbed.

FY90: Publish report on operational experience and state-of-the-art in scientific visualization for planetary exploration. Conduct demonstrations of initial concepts for exploration workstation.

FY91: Document exploratory strategies, interactive modes, and candidate formats for planetary exploration workstation.

FY92: Demonstrate mission-oriented prototype workstation and publish human-system interface guidelines.

FY93: Validate and document use of exploration workstation in simulations using realistic planetary datasets and mission operations.

3.2.2.6 Resource Allocation

	FY89	FY90	FY91	FY92	FY93	FY94
Cost $K	200	800	1000	1000	1000	1000

3.2.3 Interfaces and Controls

Man-machine interfaces technology development for lunar/planetary exploration.

3.2.3.1 Objectives

The objective of this sub-element is to determine the new technology man-machine interfaces that will be required for long-duration space flight and for living and working on the various planetary surfaces anticipated during the exploration of the solar system beyond low-earth orbit. This sub-Element builds upon results of research in "Information Needs and Integration", Section 3.2.1.The extent of the interfaces and controls that need to be included in this effort will be one of the initial areas of investigation. The results of this effort will be to enhance human productivity by providing an efficient interface between man and the space craft, the environment, tools, habitats, planetary surfaces, and other mission elements. Guidelines will be incorporated into the Operational Data Base and NASA STD 3000.

3.2.3.2 Technical Approach

Examine existing knowledge of space craft, lunar surface operations and partial-g studies with respect to the displays and controls. Perform tasks analysis and identify the effect of planetary factors (gravity, dust, atmosphere, lighting, and visibility) on displays and controls. Develop new concepts and methods for measurements and assessment of complex human-machine interactions that can be applied to allow on-line reconfiguration of controls and displays. Conduct simulations necessary to select the controls, displays, and information interfaces. Validate the selections by conducting high fidelity simulations using the integrated systems. Research results from Section 3.2.1 and from the Base R&T program will be incorporated.

3.2.3.3 Description

This task will involve defining and conducting the research needed to understand

and develop the interfaces required to allow the human to productively function in the adverse environments. The work will be based on the information needs identified in sub-Element 3.2.1 and 3.2.2. The effort will take into account the information which will be developed in sub-Element 3.2.4. A key product in the transfer of information will be the yearly workshops.

3.2.3.4 Schedule

FY89: Survey existing knowledge, perform task analysis of surface operations, identify planetary factors on display and control equipment and the users.

FY90: Identify human interfaces in detail with equipment designers of rovers, sample collectors, etc. Review state-of-the-art gloves, and effectors, robust display devices, and input devices. Develop specifications for a prototype surface workstation and a partial-g simulator.

FY91: Develop the workstation. Conduct 1-g tests on the suited subjects, evaluating the effect of gloves/end effectors on workstation size. Develop specifications for prototype tools. Refine design and construct prototype partial-g simulator.

FY92: Conduct studies with the workstation and tools in simulated partial-g. Evaluate the ease of use of input devices with respect to output devices. Evaluate partial-g simulator prototypes. Begin engineering model.

FY93: Publish design guidelines for surface EVA displays, controls and/or choose best suit alternatives. Complete functional partial-g simulator. Validate against films of lunar exploration, WETF tests, and KC-135 data.

FY94: Conduct extensive testing of workstations, habitat, and other equipment in simulator. Revise design guidelines as necessary.

3.2.3.5 Milestones

FY89: Complete survey of existing knowledge, identify equipment and display requirements and planetary factors influencing performance.

FY90: Review state-of-the-art related equipment and develop specifications for a prototype workstation and partial-g simulator.

FY91: Conduct 1-g tests and develop specifications for prototype model.

FY92: Conduct partial-g tests and evaluate input and output devices.

FY93: Publish guidelines for surface EVA displays and controls. Provide design guidelines. Complete partial-g simulator.

FY94: Report on simulator test strengths and weaknesses.

3.2.3.6 Resources

	FY89	FY90	FY91	FY92	FY93	FY94
Cost, $K	35	200	600	1000	1000	1000

3.2.4 Habitat Assessment

This sub-Element will focus on the technology needed and guidelines for meeting crew habitat requirements for lunar and planetary missions. It is anticipated that these habitats will be unique for each gravity condition.

3.2.4.1 Objectives

A major objective of this research is to determine how the crew can contribute to the assembly, construction, monitoring, logistic support and maintenance of the structures. Further, the efforts under this sub-Element will focus on the technology needed and guidelines for meeting crew habitat(s) requirements for working and meeting mission requirements on planetary surfaces. In order to plan effectively, the crew's capabilities and limitation must be considered. The habitats' design will be predicated on the capability of the crew to erect the structure with minimum mechanical equipment and with maximum speed. Thus, emergency shelters also must be included in the research.

3.2.4.2 Technical Approach

A listing of man-habitat interfaces will be identified, similar to the listing developed for the man-tended systems shown in Table 2.1-1, to define the basic topics in the design of a habitat. Existing computer aided engineering programs such as PLAID, currently used for evaluating human factors in space craft design, and mission task procedures will be used and expanded upon. PLAID includes special features such as computer "Human" models based on body segments size and joint limitations and segment manipulation capability. Crew interface requirements will be reviewed (see Sub-elements 3.2.1 and 3.2.2) as inputs to this task and guidelines developed for the crew habitats considering the various missions.

Initial guidelines will be developed for determining the crew's role in assembly and erection of the structures. Requirements also will be determined for monitoring, logistic support and maintenance of the constructed habitats. Selected testing under partial-g conditions will b e conducted to verify the guidelines.

3.2.4.3 Description

The various gravity levels and environments for each of the planet missions will present unique problems ~~in~~ meeting the objectives of this sub-Element. An understanding of the problems and the best methods of providing efficient, comfortable and safe working conditions will have to be developed. This will require analysis to define the multiple interface areas between the personnel and the habitat. An iterative process of analysis and simulations of the interfaces will be needed to assure the practicality of the arrangements and equipment, and validation of the final design. This task requires a high level of integration and is dependent on the missions, construction methods, lunar/planetary gravity conditions, and the crew's capability to perform. Significant input from other sub-Elements in Section 3.2 are required.

3.2.4.4 Schedule

FY90: Identify new construction and maintenance technology for lunar base and Mars missions and the human and computer interfaces involved.

FY91: Develop rules for interfacing humans to construction and habitat-maintenance systems and conduct simulation to evaluate the interfaces.

FY92: Refine the simulation methods and information interfaces and begin the selection of best controls and displays for controlling habitat construction and maintenance.

FY93: Conduct higher fidelity simulations and evaluate the selected controls, displays and information interfaces for habitat construction and maintenance.

FY94: Publish guidelines for crew contribution to habitat construction and maintenance the system interfaces needed to accomplish it.

3.2.4.5 Milestones

FY90:Report on new habitat construction and maintenance technologies and related human interface requirements.

FY91: Defined low-fidelity simulation systems and tests conducted to evaluate interfaces.

FY92: Developed higher-fidelity simulations; user information interfaces and methods of selection of best controls and displays for habitat construction and maintenance completed.

FY93: Conduct tests and evaluate results.

FY94: Publish guidelines for human contribution for habitat construction and maintenance and the human interfaces needed.

3.2.4.6 Resource Allocation

	FY89	FY90	FY91	FY92	FY93	FY94
Cost $K	0	100	400	500	1000	800

3.2.5. Materials and Structures

Different materials and structures for habitats on the planetary/lunar surfaces must be identified and the impact of these on crew tasks and performance determined.

3.2.5.1 Objectives

The objective of this sub-element is focused on the materials and structures necessary for living and working on the various planet surfaces. The prior sub-Element provides a basis for construction and maintenance of the habitat and the human interfaces needed to do so. The extent to which the materials and structures are unique or modular and the components which need assembly will be determined by the mission planners and the results of other research in the Pathfinder program. Special requirements which could affect the crew, by virtue of the unique materials or structures, will be identified in this sub-Element - for example: protection from cosmic radiation.

3.2.5.2 Technical Approach

Special requirements related to materials and structures will be identified from other Pathfinder Elements as they are developed. Until these requirements are more precisely defined, the detailed technical approach must be deferred.

3.2.5.3 Description

This task requires a high-level of integration and is dependent on the mission, construction methods, planetary gravity, and the crews capability to perform. Various aspects of the output from all the other Elements will have to be considered.

3.2.5.4 Schedule

This task will begin in accordance with progress in other Elements in FY89 and FY90.

3.2.5.5 Milestones

To be determined

3.2.5.6 Resource Allocation

	FY89	FY90	FY91	FY92	FY93	FY94
Cost $K	0	0	250	500	500	500

3.2.6 Health Monitoring & Instrumentation

Assess, review, evaluate and refine sophisticated, computer-based systems for routine health monitoring of the spacecraft environment, lunar/planetary habitat environment and the database of health status of the crew.

3.2.6.1 Objectives

This sub-element will focus on human-system interfaces which may be needed in human health monitoring. The biomedical research efforts being studied as part of the Humans-in-Space Element managed by Life Sciences Division,(Code E), OSSA, clearly result in a technology for human health maintenance. Insofar as data and information must be stored, processed, and retrieved for use by the crew, or subsequent utilization by NASA, a technology to provide a human-system interface is needed.

The software and human interface requirements of the Space Station Medical Computer System (SSMCS) is the baseline system for this sub-Element. The objectives include:
1) Reviewing and extending the SSMCS requirements in light of Pathfinder mission requirements, scenarios, and findings from Code E;
2) Develop, if needed, concepts for Pathfinder medical information support systems;
3) Evaluate these concepts with respect to human factors issues, with specific consideration of the need for monitoring the environment of the spacecraft or habitat for such variables as noise, radiation, or microbes, providing a easy-to-use/maintain record of crew health in transit and on lunar/planetary surfaces, and providing a database on the effectiveness of countermeasures to health problems.
4) Determine human factors issues related to the human-system interfaces for such monitoring, data collection and retrieval.

3.2.6.2 Technical Approach

The technical approach used in this sub-Element would survey Pathfinder mission requirements and state-of-the-art medical monitoring systems, especially SSMCS. The capabilities of existing systems will be rigorously characterized. The difference between existing systems and Pathfinder needs will be identified and human-system interfaces and interactions will be determined. The results of this will enhance existing medical monitoring systems and provide mission planners with analytical data and technology concepts on the capabilities of such systems and how the crew or NASA could use them in the context of Pathfinder missions. Inputs from Code E would be expected as part of the implementation.

3.2.6.3 Description

Existing health monitoring systems such as SSMCS or U.S. Navy submarine medical monitoring systems will be reviewed as to their utility and cost-effectiveness in long-duration space exploration missions. Experience from Space Station Freedom can be a major input. Human-system interfaces and data storage, utilization, and retrieval for such systems must be contrasted with mission and NASA long term needs. The utilization of expert system technology will be considered as one type of potential improvement to existing systems.

3.2.6.4 Schedule

FY90: Review Pathfinder mission analyses conducted under this Element and by Codes E and Z for human health monitoring and data storage/retrieval requirements. Coordinate with medical personnel to select and evaluate the most promising state-of-the-art systems. Examine their utility by the crew for human factors issues and by NASA for longer term utilization. Obtain Mir data, if possible.

FY91: Assess the viability of potential systems and human-system interfaces and interactions for Pathfinder. Identify technology gaps and potential expert system technology.

FY92: Initiate potential conceptual upgrades and obtain medical/user evaluations with physicians and astronauts. Modify concepts. Develop specific human-system interfaces and interactions.

FY93-94: Evaluate interfaces and interactions with medical personnel and astronauts, revise, and verify through demonstration test.

3.2.6.5 Milestones

FY90: Report on state-of-the-art systems, focusing on their strengths and weaknesses for applicability to Pathfinder missions.

FY91: Report on potential improvements to obtain viable Pathfinder capabilities for such systems.

FY92: Report on upgrades needed and human-system interfaces and interactions.

FY93 - 94: Test reports and recommendations for technology improvements.

3.2.6.6 Resource Allocation

	FY89	FY90	FY91	FY92	FY93	FY94
$K	0	100	200	200	300	300

3.3 HUMAN-AUTOMATION-ROBOTICS SYSTEMS

A major focus is development and validation of new concepts and methods for optimizing the human-automation- robotic lunar/planetary workforce. Human-automated -robotic (H-A-R) systems will be developed, as needed, to support exploratory missions and to support the needs of people working with such systems.

3.3.1 Telerobotic Operator Interface

Control of autonomous and semi-autonomous telerobotic devices and vehicles requires an interface configuration that allows variable modes of operator interaction ranging from high-level, supervisory control of multiple independent systems to highly interactive, kinesthetic coupling between operator and remote system. An appropriate interface for supervisory control modes will provide the operator with multiple viewpoints of the remote task environment in a multi-modal display format that can be easily distributed and reconfigured according to changing task priorities. For remote operations that cannot be performed autonomously, the interface will need capability to quickly switch to interactive control. In this telepresence mode, the operator is provided with a sufficient quantity and quality of sensory feedback to approximate actual presence at the remote task site.

3.3.1.1 Objectives

The objective of this sub-element is to integrate virtual workstation interfaces with remote cameras for use in telepresence and supervisory control of telerobots. Components of the interface includes head-mounted visual displays and head-coupled stereo camera systems, 3D sound displays, limb position sensing, speech recognition, and advanced pointing, object manipulation and data entry subsystems. Particular emphasis will be placed on the objective of providing remote camera imagery that is matched to the human operator.

3.3.1.2 Technical Approach

The virtual environment display system will be used to interact with a simulated telerobotic task environment. The system operator will be able to call up multiple images of the remote task environment that represent viewpoints from free-flying or telerobot-mounted camera platforms. Auditory displays and three-dimensional sound cueing technology will be developed to give distance and direction information for proximate objects and events. Switching to telepresence control mode, the operator's wide-angle, stereoscopic display will be directly linked to the telerobot 3D camera system for precise viewpoint control. Using tactile input glove technology and speech commands, the operator will directly control the robot arm and dexterous end effector which appear to be spatially correspondent with his own arm.

3.3.1.3 Description

An initial study phase will define advanced concepts for human operator control of camera viewpoint and configuration. The studies will determine camera and lens stabilization requirements for telepresence, and will also define spatial limits and thresholds of motion for free-flying or telerobot cameras. In the system simulation phase, computer graphic simulation of remote cameras systems will be created for initial user interface studies.

In the hardware/software prototyping phase, a camera positioning system capable of unrestricted motion in three-dimensional space will be developed for simulation of free-flying or telerobot camera. The simulation systems will be used to determine effective control configurations for remotely controlled stereoscopic cameras which are free-flying or attached to telerobots. Experience with these systems will also enable the development of computer-controllable stereoscopic camera positioning system with variable convergence, interocular separation, field-of-view and magnification. Technology will be developed to transmit relative camera position and orientation in real time. User interface guidelines will be developed for three-dimensional cameras through real time task simulation. Finally, an integrated remote-controlled camera system with head-tracked virtual workstation display will be demonstrated.

3.3.1.4 Schedule

FY91: Study and develop advanced concepts for human operator control of camera viewpoint and configuration.

FY92: Determine camera and lens stabilization requirements for telepresence. Define spatial limits and thresholds of motion for free-flying or telerobot cameras. Conduct user interface studies using computer graphic simulation of remote cameras systems.

FY93: Determine effective control configurations for remotely controlled stereoscopic cameras which are free-flying or attached to telerobots. Develop technology to transmit relative camera position and orientation in real time.

FY94: Conduct studies to determine user interface guidelines for 3D cameras. Construct prototype integrated camera system and user interface for use in simulated mission scenarios.

FY95: Complete studies and hardware/software integration of remote-controlled camera system with head-tracked workstation display.

3.3.1.5 Milestones and Deliverables

FY91: Develop computer graphic simulation of remote cameras systems for initial user interface studies.

FY92: Develop camera positioning system capable of unrestricted motion in three-dimensional space for simulation of free-flying or telerobot camera.

FY93: Develop computer-controllable stereoscopic camera positioning system with variable convergence, interocular separation, field-of-view and magnification.

FY94: Develop user interface guidelines for three-dimensional cameras through real time task simulation.

FY95: Demonstrate integration of remote-controlled camera system with head-tracked virtual workstation display in simulated mission scenarios.

3.3.1.6 Resource Allocation

	FY89	FY90	FY91	FY92	FY93	FY94
$K	0	0	100	200	250	300

3.3.2 Intelligent Systems Interfaces

A methodology of human-centered automation will be developed and applied to the interfaces of spacecraft and habitat intelligent systems. This effort will be coordinated with other display and information management sub-Elements in this program (see Section 3.2).

3.3.2.1 Objectives

Effective, robust human-machine systems for long-duration space missions will be designed according to a philosophy of human-centered automation. The effective authority and responsibility for mission success will rest with the crew. The crew will have control of machine resources, that is, will have ways to instruct and direct machine agents in support of crew-determined goals. Automated systems will provide support for the crew's performance of critical tasks, and will be designed so as not to force the crew to choose between completely automated vs. completely manual task performance. The crew will supervise lower-order automated systems and will therefore need support for high-level situation assessment including what the systems are doing, why they are doing it, and what they will do next.. Error detection and recovery will be well supported by the human-machine interface. Channels among humans and automated subsystems will support high-band width communication, but will not overwhelm the crew with barrages of unusable data.

The focus of this sub-Element is to develop a convergent methodology for the design of intelligent system interfaces. A secondary goal is to apply this methodology to the design of and design guidelines for a suite of operator interfaces to a significant intelligent monitoring and advisory system. An existing expert system, the integrated thermal/power cooperating system of Space Station Freedom will be used as a target system.

3.3.2.2 Technical Approach

An Interface Advisory Group will be formed as a subcommittee of the newly established Human Factors Intercenter Working Group (see Section 7.2). This group will consist of NASA scientists from ARC, JSC, JPL, and LaRC, as well as leading university researchers. The group will serve a dual function: (1) to advise operational centers (JSC,LeRC, MSFC, KSC, GSFC) with respect to current operator interface design and evaluation problems; (2) to focus applied research efforts on general operator interface problems which seem to arise in several different contexts and which will be likely to restrict Pathfinder mission options. For example,an interesting set of issues to address in the immediate future would be those connected with satellite control operations at GSFC and JPL, and related mission operations problems at KSC. Similar problems will have to be solved, with greatly reduced manpower, in lunar-base or planetary surface operations. Another interesting set of problems would be those surrounding the operator interface to proposed intelligent monitoring systems and advisory systems for Space Station Freedom thermal and power systems. Similar problems will have to solved in the context of lunar and planetary surface process control, cryogenic systems, and space-based nuclear power systems. Ames Research Center has substantial experience with operator interface issues in both of these general areas. Since the Freedom thermal testbed is located at JSC, this provides a target of opportunity for JSC operator interface research.

The major challenge to human factors engineers is to implement the technical approach in a way that allows work on the operator interface to proceed in parallel with other systems engineering efforts. This requirement implies that:

1. the operator interface must be designed and implemented in some way which converges to the final interface requirement;
2. the interface must be designed and implemented in a software engineering environment which consists of tools for rapid prototyping, user-testing, and iterative refinement;
3. the interface design team must mock-up their own system models, as well as their own expert systems, even though these will be rough approximations or place-holders at first;
4. the interface must be user-tested under scripted scenarios, preferably critical task scenarios reflecting difficult off-nominal conditions.

Thus, task analysis, interface prototyping, user-testing, and iterative design must be carried out from the beginning of the project at whatever level of approximation to the final task environment is feasible.

A four-year effort is proposed. The main product would be a document describing the convergent operator interface design methodology. Also, a specification for the operator interface suite would be produced. In addition, a prototype interface suite would be produced, along with various task analysis, interface design, and user-testing tools and their documentation.

3.3.2.3 Description

A number of field studies and analyses have been conducted on the human role in highly automated systems. In NASA, the Aeronautics Safety/Automation initiative, begun in FY1989, applies lessons learned to the cockpit and Air Traffic Control environment. Under a human-centered automation technology, it becomes the human's role to protect and manage the automated system by preventing or accommodating to unplanned variability. Thus, the operator must infer what the automated system is doing, why, and how well it is progressing. Unfortunately, many times the interfaces the operator has are insensitive to such demands. Human error results. Workload may increase during periods of greatest risk. System casualties may and do result in highly degraded performance.

A properly designed interface should provide users the information needed to get the job done. Several methods and techniques will be used to develop interfaces for intelligent systems and are described in the next section.

3.3.2.4 Schedule

FY 90: A survey and comparative evaluation will be conducted of existing technical approaches for task analysis, task simulation, interface prototyping, and user-testing. A detailed technical plan will be written for the work to be done during FY 91-93, assessing software, hardware, documentation, and manpower requirements.

FY91:Task Analysis - One of the goals of the planning effort is to identify a method of task analysis suitable for use in convergent design of the operator interface. One full-time human factors engineer will be identified at each of LeRC, JSC, and MSFC. to support the task analysis effort. These individuals should be members of the respective expert system demonstration teams. The task analysis effort will be led by the appropriate members of the Interface Advisory Group.

FY91-92: Task Simulation - Based on the task analysis, and overlapping it, the task simulation effort will begin. The goal is to develop software to simulate critical tasks involving diagnosis and fault-recovery, start-up, shut-down, and other difficult or off-nominal tasks. The task simulation effort will be led by the appropriate members of the Interface Advisory Group.

FY92-93: Interface Design - A one-year effort is proposed for designing and implementing a suite of prototype interfaces. Specification of the number of displays, level of integration, and correspondence to thermal and power system components will require careful analysis. The goal is to have prototype interfaces which can be driven by the task simulation software for purposes of user-testing.

FY92-94: User-Testing - User-testing overlaps and interacts extensively with interface prototyping and task simulation. This is because the methodology envisioned is one of iterative design and extensive user-testing in simulated tasks. The anticipated users will include thermal engineers, power engineers, and astronauts. Systems appropriate for user-testing will also be appropriate for demonstration to management, outside evaluators, etc. The task simulations and interface prototypes will be refined, based on user-testing and on increasingly detailed information about the target systems. The final interface specifications should be available soon after the design of the target systems (including AI systems) becomes stable.

3.3.2.5 Milestones

FY90: Detailed plan for tasks to be performed in FY91-93 period with a detailed Work Breakdown Structure, based on a review of Space Station Freedom's targeted expert system.

FY91-92: Software and documentation of critical tasks involving diagnosis, fault-recovery, start-up, shut-down, and other off-normal tasks. An operator interface functional specification will be delivered.

FY92-93: Design and implementation completed of prototype interfaces which can be driven by software (developed in FY91-92).

FY94: The final product will be a formal specification of the operator interface suite, suitable for delivery to a contractor who will produce the final software product. Other deliverables will include documentation of the convergent design methodology, various design and user-testing software tools and their documentation, and prototype interfaces.

3.3.2.6 Resource Allocation

	FY89	FY90	FY91	FY92	FY93	FY94
$K	0	200	600	800	900	800

3.3.3 Human-Automation-Robotic Information and Control Flow

The effort in this sub-Element focuses specifically on the visualization of information and control flow in distributed human-automation-robotic (H-A-R) systems.

3.3.3.1 Objectives

The aim is to develop and test H-A-R systems design and evaluation methods based on valid cognitive models of human performance. Perceptual and strength-and-motion models may also be incorporated. The intent is to produce tools which will be useful to systems designers, including

-- rapid prototyping methods
-- modeling frameworks that interface with the engineering environment
-- validation of human-machine system models in realistic task environments

The work to be done under this sub-Element specifically focuses on the visualization of information and control flow in distributed H-A-R systems.

The program will explore graphical representations that allow designers to visualize the flow of processing and identify bottlenecks that restrict throughput. The model and its graphical representation must also provide clues as to how the situation could be modified to make better use of the operator's processing resources.

3.3.3.2 Technical Approach

An integrated formalism for describing distributed information processing systems has been developed by C.A.R. Hoare and his colleagues at Oxford University. Several researchers in the U.S. have been exploring the utility of Hoare's approach, including Dr. Art Farley (University of Oregon), who is currently supported by NASA through the Systems Autonomy program. Other research efforts are underway at IBM Watson Laboratories, Tektronix, Cornell University, and Auburn University. In addition to the mathematical theory, Hoare's group has developed a related programming language, Occam, and a hardware system, the Inmos Transputer. Together, the mathematical theory, programming language, and Transputer hardware provide a comprehensive framework within which simulations of complex H-A-R systems can be described, programmed, and simulated. This framework is mathematically precise, flexible, and inexpensive. Several implementations are currently available. The Oxford group is extending the mathematical theory to incorporate stochastic and temporal aspects of distributed processes. These theoretical extensions, when complete, will make the system much more useful for the analysis of human-machine systems. However, the Occam programming language (or related dialects of C) and the Transputer hardware make it possible to handle stochastic and temporal aspects of HMI at the level of simulation, without waiting for the completion of the theoretical work.

The Knowledge Systems Laboratory at Stanford has also developed a simulation system for rapid prototyping of distributed system designs. The multiprocessor components represent detailed models with respect to communication facilities and coarse models with respect to purely uniprocessor operations. Passing messages or manipulating shared memory result in communication events. This approach has been used successfully to study distributed systems performing complex tasks within acceptable time constraints. Since the system is basically object-oriented, it is possible to build libraries of simulated components which are minor variants on a theme. There are many other approaches to object-oriented system simulation, ranging from descendants of the Navy's Steamer project to the Balsa-II and PARET computational modeling and visualization systems.

Our initial work on H-A-R systems will focus on the systematic comparison of these systems, and the evaluation of their usefulness as tools for the modeling and visualization of information and control flow in distributed H-A-R systems. The later stages of the program will move toward more complete system development, with refinements occurring in the context of realistic operational tests in high-fidelity simulation environments.

The program will explore graphical representations that allow designers to visualize the flow of processing and identify bottlenecks that restrict throughput. The model and its graphical representation must also provide clues as to how the situation could be modified to make better use of the operator's processing resources.

3.3.3.3 Description

A Resource Constraint Model will be developed that specifies the architecture of the human information processing system. This model will be augmented by graphical representations of its functioning so that designers can visualize and predict the impact of their designs on information throughput. As a result, human factors engineers will be able to make more precise, quantitative statements about the impact of system design on human operator performance.

3.3.3.4 Schedule

FY90: Complete literature search and define technical approach.

FY91: Define task/model interface and system architecture; choose three mission tasks to analyze and simulate in expert systems.

FY92: Define graphics interface requirements for visualization of information flow; complete task/model framework.

FY93: Complete information and control flow visualization for three tasks.

FY94: Complete graphics visualization for temporal and stochastic information and demonstrate for three mission tasks.

3.3.3.5 Milestones

FY90: Mathematical basis for qualitative process modeling developed and documented in a paper. Literature search completed for existing relevant models

FY91: Definition of task/model graphics interface requirements for visualization. Task/model architecture completed and report prepared.

FY92: Technical report on task/model framework, mathematical model framework, and visualization approach.

FY93: Demonstration software available for three mission tasks (qualitative flow model). Task analysis and simulation completed for three mission tasks

FY93: Graphics visualization completed of information flow enhanced for temporal and stochastic information. Validation experiments completed for three tasks. Demonstration software with temporal and stochastic enhancements available.

3.3.3.6 Resource Allocation

	FY89	FY90	FY91	FY92	FY93	FY94
$K	0	250	400	800	800	800

3.3.4 H-A-R Systems Measurement and Validation

Hardware and software systems will be systematically compared for suitability for implementing both information/control flow visualization software (see Section above) and precise computational models of human-machine systems (Section 3.2).

3.3.4.1 Objectives

The objectives of this sub-element are (1) to conduct a systematic survey of available hardware and software systems to support the work proposed under cognitive models and the above Section and (2) to specify a low-cost, flexible simulation system for the implementation of H-A-R systems models in order to evaluate systems designs and architectures quantitatively.

3.3.4.2 Technical Approach

The most attractive approach to meet the Objectives is to focus on the CSP/Occam/Transputer system developed at Oxford University by Hoare, et. al. This approach offers a mathematically precise and extensible framework for complex systems analysis; a variety of programming languages for writing simulations of distributed systems and a low-cost hardware substrate for simulation, information and control flow visualization, and part-task experimental environments.

Software vendors offer a variety of developments systems. Research is needed to determine which of these is best suited to an integrated modeling, simulation, and visualization effort such as the one described above in the above Section. A Transputer Development Systems (TDS) consists of a folding editor and a number of utilities (compilers, network loader, and file utilities). At this moment there are transputer development systems for PC, Sun, Macintosh, Apollo and Vax from different manufacturers. They all look alike, but they might differ on certain crucial points. Debugging a distributed system with a large number of transputers is a difficult problem. However, at this moment there are network analyzers and symbolic debuggers available that detect faulty processors or deadlocks.

Although there are many possible combinations of hardware and off-the-shelf software available, it is worthwhile to investigate them carefully. An intelligently chosen system will integrate Pathfinder research described under a number of the sub-Elements in Sections 3.2 and 3.3 and will provide the sophisticated simulation architectures needed to test matured technologies in the Space Human Factors Program (see following Sections). Further, a well-chosen system could become a standard tool among all NASA Centers and its contractor/ university support, thus facilitating portability of software and technology transfer.

3.3.4.3 Description

A systematic survey of available hardware and software will be conducted to support the proposed work in cognitive models and visualization and to obtain a specification of a low-cost, flexible simulation system for the implementation of H-A-R system. Hardware and software will be compared systematically for suitability for implementing both information/flow control visualization software and precise computational models of human-machine systems. The goal is: (1) to find a low-cost system which provides for mathematically well-founded modeling of H-A-R systems; (2) provide a low-cost and flexible development environment; (3) to obtain the potential for a sophisticated moderate fidelity task simulation; and (4) to obtain the potential for a realistic delivery system for NASA, contractor, and university end-users.

3.3.4.4 Schedule

FY90: Initial hardware and software requirements review and analysis.

FY91: Initial hardware configuration determined.

FY92: Software specification determined. Functional specification completed

FY93: Laboratory testing of functional system

3.3.4.5 Milestones

FY90: Initial hardware/software requirements documentation

FY91: Initial hardware and software functional specification

FY92: Complete system configuration and procurement specification

FY93: Validation experiments completed.

3.3.4.6 Resource Allocation

	FY89	FY90	FY91	FY92	FY93
$K	0	100	300	600	600

3.3.5 H-A-R Systems Testbed

A Human Interactive Systems Testbed (HIST) at Ames Research Center will be used to test the developed technologies in intelligent distributed systems, developed under this Program and others. Using HIST, it will be possible to provide guidelines for function allocation among Pathfinder crews, engaged in exploration missions, and various (proposed) intelligent support systems. These guidelines will be incorporated into the NASA Aerospace Human Factors Database and will be a valuable input to Pathfinder mission planners.

3.3.5.1 Objectives

Use the ARC Human Interactive Systems Testbed to develop realistic simulations of Pathfinder mission tasks. Apply model-based tools developed under sub-Elements: Cognitive Models, Human Factors Design and Analysis Tools, Information Needs and Integration, Telerobotic Operator Interface, Operator Interface to Intelligent Systems, and H-A-R Information and Control Flow Visualization in order to design and test operator interfaces and intelligent aiding systems. Use model-based visualization and measurement tools to enable mission planners to make well-founded technical decisions about the feasibility of alternative human-automation-robotics systems designs and function-allocation schemes for Pathfinder missions.

In the long term for Pathfinder implementation phase (FY1995-2005), this capability will allow low-cost research on the implementation and testing of actual system prototypes and technology integration/verification.

3.3.5.2 Technical Approach

This sub-Element will support technology development activities, described above in preceding sections. Based on research performed in the preceding section (reference CSP/Occam/Transputer research) and supporting research in distributed systems, artificial intelligence, systems analysis and other research developed in the R&T Base, HIST will be specified.

3.3.5.3 Description

A NASA center for research in distributed intelligent systems will be developed. The physical location of the HIST will be the high bay of the Human Performance Research Laboratory, Ames Research Center. The focus will be technology test and evaluation in support of Space Human Factors technology development. Hardware and software will be provided by previously cited sub-Elements in this Program and base R&T research.

3.3.5.4 Schedule

FY89: Initial analysis of HIST requirements.

FY90: H-A-R Pathfinder research begin; incorporate results into HIST requirements.

FY91: Functional specification developed.

FY92: Research products from other sub-Elements and R&T Base integrated into the Testbed site and facility.

FY93: Testbed operational and initial testing started.

FY94: Analysis and testing of end products of H-A-R research.

3.3.5.5 Milestones

FY89: Feasibility analysis of requirements documented.

FY90: Functional requirements documented; cost analysis completed.

FY91: Report on specification and update of test plan for evaluation of H-A-R research products.

FY92: Initial operational capability (IOC) of HIST.

FY93- 94: Reports of research results.

3.3.5.6 Resource Allocation

	FY89	FY90	FY91	FY92	FY93	FY94
$K	200	200	800	(cost to be determined)		

4.0 CONTRACTING PLANS

The goal of this Project Plan vis-a-vis contracting plans is to provide a capability for development of technologies which support effective human performance during transit and exploration activities. Close collaboration with U.S. universities and private industry will support the development of these technologies and ensure present and future U.S. competitiveness in space technology innovation and development.

4.1 OVERVIEW

Close collaboration between NASA, universities and private industry is needed to accomplish the goals of this Plan. As seen in Table 2.3.1-2, the critical skills required to support the technology development from the staff at NASA Centers from FY1989-1994 is limited. Assistance from contractors and universities, via procurements and grants is necessary to accomplish the technology development plan.

The character and quality of the support to NASA Centers will be determined each year as part of the semi-annual review process. Therefore, the actual numbers in Table 4.1-1 will be changed to reflect the experience and progress in achieving the Plan's and budget available for the upcoming fiscal year. In some of the tasks, a contract will be negotiated to provide diversified, professional talent in the areas of engineering, computer sciences or modeling. Both on-site and off-site support may be required. Grants with academic institutions will be made, as needed, to provide baseline technology and understanding of specific, complex issues in human factors for the missions in the Pathfinder program. Every attempt will be made to ensure a reasonable balance between NASA staff and outside activities, especially to provide a continuity of human resources over the life of this Project.

In conducting the assessment, an evaluation of critical in-house skills required for specific technical areas of emphasis was developed. A further evaluation of the relative supporting contractor and academic roles was conducted. It was determined that an on-site support contract will be required to provide the required range of technical expertise and support. A contract will be negotiated to provide diversified, professional talent in the areas of engineering, computer modeling, and physical/life sciences. Technical skill such as that provided by electrical, electronic, and mechanical technicians will also be required. An attempt will be made to ensure a reasonable balance between in-house and outside activities, while ensuring that key in-house technical expertise be given highest priority.

4.2 COLLABORATION MECHANISMS

This Program will utilize many traditional and NASA Center-unique legal mechanisms to collaborate with U.S. universities and industries on Space Human Factors activities. Available mechanisms are divided into three categories: Standard Agreements, Small Business Innovation Research

Program, and Space Act Agreements.

4.2.1 Standard Agreements

Under the 1978 Federal Grant and Cooperative Agreement Act, Congress standardized the ways NASA and all other federal agencies purchased property and employed persons. The Act provides three mechanisms for federal agencies use to carry out procurement activities: Procurement Contract, Grant, and Cooperative Agreements.

Procurement Contract: NASA uses the procurement contract to acquire services and property for its direct use and benefit through purchase, lease or barter (31 U.S.C. 6303). NASA solicits requests for proposals (RFPs) where the extent of agency guidance is definitive. Unsolicited proposals relevant to agency mission requirements are also accepted for both general and NASA-specified program goals.

Grant Agreement: NASA uses the grant agreement to pay or otherwise compensate the recipient to carry out an activity within NASA's charter. Under a grant agreement, NASA does not benefit directly and does not require substantial involvement to carry out the activity (31 U.S.C. 6304). The grant agreement is NASA's preferred instrument for support or stimulation of basic research of interest to the agency.

Cooperative Agreement: The cooperative agreement permits NASA to pay or otherwise compensate the recipient to carry out an activity within NASA's charter and work closely with the recipient (31 U.S.C. 6305). Cooperative agreements are used generally for research projects possible only through extensive joint NASA/recipient activities.

4.2.2 Small Business Innovation Research (SBIR) Program

The Small Business Innovation Development Act of 1982 enables NASA and other federal agencies to conduct SBIR programs to stimulate technology innovation in the private sector, strengthen the role of small businesses in meeting federal research and development needs, increase commercial application of federally supported research results, and foster minority and disadvantaged participation in technology innovation (15 U.S.C. 638).

NASA determines the technical topics and subtopics to be included in its SBIR solicitation and chooses awarders according to established criteria. Phase I and Phase II SBIR programs use the procurement contract to fund awarders. Phase III activity is conducted by small businesses using nonfederal money to pursue commercial applications.

4.2.3 Space Act Agreements

Space Act Agreements derive authority from the National Aeronautics and Space Act of 1958. By definition, Space Act Agreements do not fall within the scope of legislatively defined procurement, grant, or cooperative agreements and are bound only by parameters set by NASA Management Instructions (NMIs).

Memorandum of Understanding (MOU): MOUs are used by NASA to enter into a relationship with another party, expressing an intent by the parties to negotiate and outline details toward a fuller agreement. MOUs are used for establishing relationships between NASA field installations, with industries, universities, nonprofit, or other governmental entities. With a profit-making entity, MOUs can be used by NASA for either reimbursable or nonreimbursable arrangements.

Technical Exchange Agreement (TEA): The TEA, a recently developed mechanism sponsored by NASA's Office of Commercial Programs (OCP), facilitates special relationships between NASA and domestic industries. Under a TEA, NASA and a company agree to undertake a ground-based research project that will result in potential application to commercial space. The TEA provides an incentive, at minimal risk, for a non-aerospace firm to become familiar with space technology and apply findings to the firm's product line. Each party funds its own participation and shares the research results.

Joint Endeavor Agreement (JEA): The JEA, another OCP-sponsored mechanism, is an agreement between NASA and a firm to encourage early space ventures and demonstrate the use of space technology to meet marketplace needs. The firm selects an experiment and develops the required flight hardware at its own expense. As incentive, NASA agrees to provide free Shuttle flights for experiments meeting basic criteria and allows the firm to retain certain exclusive rights in patents and proprietary information that may result from activities conducted under the JEA. NASA receives sufficient data to evaluate the significance of the experiment's results.

NASA-Centers' Agreements: NASA Centers have evolved different ways and means to obtain cooperative working arrangements with universities and private industry. For example, Ames Research Center established the Ames Joint Enterprise for Aerospace Research & Technology Transfer (Joint Enterprise). The joint Enterprise uses a consortium approach to involve industry from the onset to develop commercially applicable projects. Using a university or nonprofit organization to broker NASA and industry interests, the Joint Enterprise mechanism establishes all parties' rights and obligations prior to agreement.

The University Consortium is another Ames mechanism that allows university faculty and students to work with Ames scientists and engineers on short-term, novel research projects. Special agreements provide for reciprocal use of services, personnel, equipment, and facilities between Ames and the 136 distinguished member universities.

4.3 IMPACT ON CURRENT PROGRAMS

Because of the unique collaborative agreement mechanisms indicated above, NASA Centers have established significant leverage of its research program efforts through industry and university participation. The anticipated scope of the outside component of the proposed Pathfinder efforts is within the capability of the current supporting contracting and grant structure.

5.0 FACILITIES PLANS

5.1 OVERVIEW

This section contains a brief description of all NASA facilities foreseen to play a role in the Space Human Factors portion of the Pathfinder Program. Both the existing and planned capabilities of the Centers are addressed to the extent possible.

In this plan, the facilities have been divided into two general classes: (1) laboratories and advanced computing capabilities, and (2) demonstration and test facilities. Laboratories and the advanced computing facilities will support the development of innovative concepts and the underlying knowledge necessary for the achievement of the Pathfinder technology objectives. The demonstration and test facilities (i.e., technology "testbeds") will be used to validate the scientific knowledge and provide convincing, risk-reducing demonstrations of the innovative Pathfinder technology components and systems.

5.2 AMES RESEARCH CENTER

The Ames Research Center consists of two installations, referred to as Ames-Moffett and Ames-Dryden. Ames-Moffett, which will provide the bulk of research capabilities to support the Pathfinder program, is located on 422 acres of land adjacent to the U.S. Naval Air Station, Moffett Field, California. About 2,000 civil service employees and an equivalent number of contractor employees are employed at Ames. The estimated replacement value of the installation is $2.1 billion.

5.2.1 Laboratories and Computing Capabilities

Resident facilities are described in terms of their capabilities, with emphasis on the major research areas in the project:

Human Performance Research Laboratory (HPRL): The Human Performance Research Laboratory is a new facility which is under construction at Ames and whose purpose is to support research and technology aimed at improving the human factors of aerospace systems. The two story building, which encompasses 65,000 square feet, will contain offices and state-of-the-art laboratories for approximately 180 scientists, engineers and supporting technical and administrative staff of the Ames Aerospace Human Factors Research Division, and an 80' by 150' (12,000 square feet) high bay area. The latter is intended to house a testbed for human-interactive systems such as EVA/suit and be used for validation of autonomous systems technologies.

Virtual Interactive Environment Workstation Laboratory (VIEWS): VIEWS consists of a wide-angle stereoscopic display unit, glove-like devices for multiple degree-of-freedom tactile input, connected speech recognition technology, gesture tracking devices, and computer graphic and video image generation equipment. Head motion of the user is tracked by a helmet-mounted sensor and the derived position and orientation data is used to update the displayed stereo images in response to the users activity. As a result the displayed imagery appears to completely surround the user in 3-D space and contains full motion parallax, motion perspective and binocular parallax information.

Life Sciences Laboratories: supporting life sciences, biomedicine, and basic life support research and technology. Several facilities are concerned with the determination of human physiological and psychological response to simulated space flight conditions. The research contained in these facilities may influence mission requirements, scenarios, or guidelines and, as such they are sources of indirect input.

The Man-Carrying Rotation Device: used to assess the physiological effects of motion on human subjects and their ability to perform various tasks. The 20-g Human Centrifuge is the only man-rated centrifuge in NASA. Investigators use it to examine the effects of altered gravitational forces on biological system and instrument packages in order to determine their qualification for flight.

Automation Sciences SADP Brassboard Integration Laboratory: The Laboratory is used to develop, integrate, and validate knowledge-based systems technology that will thereafter be demonstrated on Space Station testbeds at other NASA Centers. It provides a realistic operating environment to test Expert Systems and other knowledge-based systems technology used in a control, rather than advisory, application

5.3 JOHNSON SPACE CENTER

The Johnson Space Center (JSC) has played a major role in manned spacecraft design, development, testing, and operations since the Gemini program. The stringent test requirements for flight qualification and the astronaut presence at JSC have led to the construction of some very specialized laboratories and test facilities. These facilities will be used in the development of Pathfinder Space Human Factors technology, in addition to their test and training roles for ongoing programs. The facilities are described below.

Weightless Environment Training Facility (WETF): The WETF is housed in Building 29 and is under the supervision of the Man-Systems Division. Like the NBTF at Ames, it provides simulation of a weightless environment through underwater testing and is used in the evaluation of space suits and other EVA equipment. The facility consists of an in-ground tank 78' x 33' x 25' deep, holding approximately 500,000 gallons of heated water, with associated water filtration/chlorination system. An environmental control system (ECS) is able to supply thermal regulation and breathing air for a maximum of three suited-subjects.

Numerous mockups have been made for use in the WETF, for evaluation of past and current space hardware configurations, including a full size mock-up of the shuttle payload bay.

KC-135: One KC-135 Airplane, tail #NASA930, is housed at Ellington AFB, about 15 miles from the Space Center. The plane is flown in parabolas which provide 20-25 seconds of weightlessness (zero-g). The flight parabolas can be varied to provide a partial-g environment. Approximately 40 parabolas are flown on a typical mission. The flights have been used for astronaut orientation to zero-g, as well as in space life sciences research and engineering development. EVA-related tasks performed in the KC-135 to date include the biomechanical evaluation of suit mobility with the Cybex dynamometer and suit don/doff.

Anthropometry and Biomechanics Laboratory: The Anthropometry and Biomechanics Laboratory is located in Building 29 and covers 1,600 square feet. The primary functions of the lab are the determination of astronaut size and reach envelopes to be used in space vehicle design, and the determination of astronaut musculoskeleton strength, power, and endurance. Investigation of 1-g biomechanics are performed, and protocols outlined for associated zero-g simulations. The facility is equipped with a PDP-11/44 data acquisition/reduction system with 32 channel capability and associated terminals and printers; a force/torque sensor; a force plate, waterproof to 60 feet, two Cybex dynamometers; and electromyographic equipment. The electromyography system is being upgraded with telemetry equipment, and procurement is underway on a 3-D video motion tracking system with high speed capability.

Crew and Thermal Systems Test Chambers: These are four environmental chambers housed in Buildings 7 and 32. The first of these is the 8-Foot Chamber. It is 8' in diameter and approximately 14' long, with a horizontal axis. It is used primarily in the parametric evaluation of portable life support systems. The "can man" provides control of simulated metabolic processes such as CO2 production, O2 consumption, heat production, and humidity level to evaluate PLSS subsystems.

The 11-Foot Chamber is a man-rated suit test facility in which suits are metabolically loaded. It is approximately 19' long, with the entrance and two successive "locks" at one end. The interlock houses the suited-subject, while the outerlock is held at an intermediate altitude to contain rescue observers. The chamber is equipped with total life support systems for the subjects (up to two), treadmills, and a weight release system. Currently it is used to train the shuttle crew, using EVA mission simulations. A thermal vacuum space suit gloves test chamber is attached to the outerlock.

Chamber B is used for thermal vacuum qualification of space hardware with vacuum pumping capability to 10-6 torr and liquid nitrogen cold walls. It has a 25' diameter and is 26' in height. As in the 11-Foot Chamber, there are two man locks, side-by-side, one containing a rescue crew at intermediate altitude, and one used as the crewman's airlock.

Chamber A, the largest of the chambers with a 55' diameter and a 90' height, is not currently man-rated. It is currently used for unmanned testing of space hardware. This chamber also has dual manlocks which can be used as independent altitude chambers when the inner door is bolted. The chamber has LN2 cold walls and can provide simulated albedo and planetary radiation.

The Graphic Analysis Facility (GRAF), located in Building 15, includes hardware and software for static and animated analyses of spacecraft design, flight operations, and human activities. A VAX 11/785 and a number of state-of-the-art graphics workstations are employed to provide full graphics analysis capabilities with colored prints and videotapes as outputs. The unique aspect and greatest advantage of the GRAF over other computer graphics labs lies in its software, which enables the user to create human bodies to specified sizes or percentiles, and to position the bodies in a goal oriented manner rather than joint by joint. Animation based on a sophisticated man model is partially automated. Lighting models are incorporated for use in visibility, shadowing, and illumination tests.

The Orbiter Crew Compartment Trainer (CCT) and the Orbiter Full Fuselage Trainer (FFT) are two high-fidelity representations of the Orbiter crew station and payload bay. They are used for training for inflight operations and for verifying that the necessary volume, light, restraints, connections, etc. are available for flight experiments and equipment. These may be used to test proposed flight experiments in support of Pathfinder research.

The Manipulator Development Facility (MDF) is a realistic simulation of the Remote Manipulator System for development of payload operation, procedures, and hardware. It is available for human-teleoperator interface analysis. Studies have been conducted on the use of vocal commands for camera controls and on force feedback, among other things.

5.4 LANGLEY RESEARCH CENTER

The Langley Research Center has had a remarkable history, not only during three decades as NASA Langley Research Center, But in an earlier period as well: during Langley's four decades as the flagship research facility of the National Advisory Committee for Aeronautics (NACA). Nearly every aircraft and spacecraft that the United States has flown carries with it some contribution from the work of Langley researchers. The nation's manned space effort was spawned at Langley and Langley continues to have a strong role through research and technology programs in space systems. Langley's work force consist of more than 5,000 people -- civil servants, support service contractors, university personnel, and members of other government agencies. Located in Hampton, Virginia, Langley is adjacent to Langley Air Force Base, Headquarters for the Tactical Air Command, and shares airport facilities with the Air Force. Langley has extensive aeronautical and space test facilities, many of which are unique in the world. Langley has been designated the lead center for Automated Space Construction in the Pathfinder Project.

The following facilities are those which are felt to be particularly appropriate for support of the Pathfinder Human Performance and EVA/Suit elements.

Human Engineering Methods Laboratory: The Human Engineering Methods (HEM) Laboratory has been established to exploit measurement technology to assess the effects of advanced crew station concepts on the crew's ability to function without excessive mental workload, stress, or fatigue. The laboratory provides the capability for measurement of behavioral and psychophysiological responses and performance of the flight deck crew. The facility comprises state-of-the-art bioinstrumentation, as well as computer-based physiological data acquisition, analysis and display, and experimental control capability. Software has been developed which enables the demonstration of workload effects on the steady-state evoked brain response and transient evoked response signals, as well as monitoring of electrocardiographic (EKG), Electromyographic (EMG), skin temperature, respiration, and electrodermal activity. The Langley-developed oculometer capability has been integrated with the other physiological measurement techniques. Subjective rating and secondary task methods for assessing mental workload have also been implemented. A computer-based criterion task battery is available for preliminary testing (with human subjects) of workload techniques that are being validated prior to evaluation and application in the simulators. Satellite physiological signal conditioning and behavioral response capture stations are located at the simulator sites to provide human response measurement support for flight management and operations research. The HEM Laboratory has been used largely for aeronautics R&T, however, Its unique capabilities are equally applicable for Space R&T and the Pathfinder Human Performance element.

Crew Station Systems Research Laboratory: The LaRC Crew Station Systems

Research Laboratory (CSSRL) is at the cutting edge of research into the "all-glass" crew station and its integrated electronic systems. Here, research and development activities on advanced display media, display generation techniques, information management technologies, and integrated crew station systems are conducted. Man/machine interface studies can be conducted to evaluate the performance of man in conjunction with advanced electronic control/display interfaces and concepts. Major elements of the CSSRL are the Advanced Display Evaluation Cockpit (ADEC), which is a reconfigurable research cab, a simulation host processor, high-performance raster display generators (capable of generating 2-D, 3-D, and stereo 3-D pictorial displays), a variety of high-performance display media (color CRT's and monochrome and color flat-panel displays), and electronic input/output devices. The CSSRL is undergoing a major upgrade to provide advanced capabilities for research on experimental pictorial displays using the following techniques: projected displays (stereo and non-stereo), panoramic pictorial displays, and helmet-mounted displays (HMD's). The CSSRL has been used largely for aeronautics R&T, however, its unique capabilities are equally applicable for Space R&T and the Pathfinder Human Performance and EVA/Suit elements.

Aircraft Cockpit Ambient Lighting and Solar Simulator: The LaRC Aircraft Cockpit Ambient Lighting and Solar Simulator (ACALSS) in an ambient lighting simulation system, implemented in conjunction with the CSSRL above. It consists of an integrating light elliptical shell surrounding the ADEC simulator cab. Studio TV lights and a solar source provide the lighting sources, and can be used in combination with reflector panels to direct the simulated sun at the flight deck display panel. Both the direction and color are under computer control. The simulator can reproduce the cockpit ambient light from darkness through 10,000 foot candles (direct sunlight conditions) with diffuse sky backgrounds (sunrise to dusk). Display Research Laboratory: The LaRC Display Research Laboratory (DSL) is a instrumentation-van-based display lab which houses an experimental non-virtual work station research and development area, including advanced display generation and input/output hardware, as well as an interactive video disk production facility. The interactive video disk production facility is unique in that it contains full video imaging, processing, and editing equipment along with video direct read after write (DRAW) disk and software authoring facilities for creating laser-optical disks and associated interactive software in-house. Using this facility, research on advance, non-virtual work stations, including human access to interactive visual data bases can be explored as part of the Pathfinder Human Performance and EVA/Suit Elements. The DRL has been utilized to develop an advanced Space Station Work Station for JSC as a part of the Space Station Advanced Development Program.

Automated Space Assembly Facility (ASAF): The ASAF is an automated construction testbed facility already under development at LaRC using Space Station advanced development and space R&T funds. It will provide a means to evaluate and develop telerobotic systems and operational procedures for automated construction in space. It is equally applicable to in-space and planetary habitat automated assembly and construction research and development. The capability will evolve to allow testing of a wide range of space/planetary structure concepts, including utilities and facets of installation, high capacity joints and assembly, and service and repair of platform. vehicles, and habitats. The facility will incorporate mobility for the robotic manipulator, and will be sufficiently flexible to accommodate other construction concepts (i.e. space cranes, berthing/joining of large modules). In addition, it will support system integration and coordination of several manipulators, such as multiple arms and the human interface to automated construction tools.

5.5 FACILITIES ASSESSMENT

Existing and planned NASA resident facilities, ARC, JSC, and LaRC are adequate for developing and testing the base technologies for many of the Space Human Factors Project products, in the form of components and subsystems, with one exception. Test requirements and facilities have not been defined for evaluation of hardware under conditions of partial-g (1/3-g, 1/6-g). Test requirements will evolve from mission requirements definition.
In the latter half of the ten-year Pathfinder Program, efforts will concentrate on the integration of components and subsystems into subassemblies and larger systems. There is need for the development of an Integrated Systems Testbed (ISTB) in which such integrated systems can be tested for satisfactory performance in the simulated mission environment.

The facilities of NASA and other federal agencies will be used to the fullest extent. Facilities of Pathfinder program, university grantees, and sub-contractors will also be utilized where possible. Only where existing facilities are inadequate and cannot be economically upgraded to meet the test requirements, will the construction of a new facility be considered.

6.0 IN-SPACE RESEARCH AND TECHNOLOGY

The NASA In Space Program is in the process of developing a Humans-in-Space section to take into account the need for flight testing. When that program has completed its definition phase, expected in Spring 1989, this Project Plan will be modified to reflect any specific Pathfinder flight experiments.

7.0 TECHNOLOGY TRANSFER PLANNING

7.1 OVERVIEW

The broad technical challenges, limited resources, and multi-center aspect of this Project, and of the Pathfinder Program in general, demand that effective technology transfer mechanisms be developed from the beginning of the program and that a concerted effort be maintained to ensure that these mechanisms achieve the desired result. The Program Manager will coordinate research efforts with the Inter-Center Working Group. Further direct collaboration with development or mission lead centers will be established to ensure a close tie between the research activities and the requirements of the project, This will ensure the ultimate transfer of technology to flight development centers such as JSC will be effective and cost-efficient. A yearly workshop on Space Human Factors program research tasks and results, will be conducted to assist in peer review and technology transfer. Results will influence the Pathfinder program, as documented in the annual update to this Plan. Personnel from NASA, other federal government agencies, industry and universities will be encouraged to attend.

7.2 INTER-CENTER RELATIONSHIPS

Coordinated effort among the Centers is mandatory since it is economical and provides an improved resource base (personnel and facilities) to accomplish the effort. The opportunities for such coordination will be made apparent to researchers at all centers by the project element managers at the centers. The project element manager will maintain regular communications among themselves and with the Program Manager. The formal procedure for the planning, monitoring, and reporting of task efforts is outlined in the Management Section of this document (Section 2.2).

7.3 RELATIONSHIPS TO R&T BASE

An assessment of the relationship between the R&T base and the Pathfinder elements has been conducted to ensure technology transfer between these project elements and to avoid duplication of effort. A reassessment will be conducted annually, concurrently with the Project Plan updating (see also Section 7.3).

7.4 TECHNOLOGY DEMONSTRATION

Where appropriate, the Centers will use testbeds or technology development demonstrations to evaluate the level of maturity of major technologies under development. Proof-of-concept demonstrations also may be conducted to assist in transferring the technology to a development center. Development centers and the Astronaut Office will be encouraged to participate in these demonstrations to foster teaming and to develop confidence in the technology developed. These testbeds will be research and technology development in nature and will not duplicate, or otherwise compete with, higher fidelity systems integration, engineering, or operations oriented testbeds which may be developed at the development centers. As research facilities, however, they may be made available to other centers as well as to industry and universities in support of related technology development requirements.

7.5 INDUSTRY RELATIONSHIP

7.5.1 Overview

An important component of the nation's civilian space R&T capability resides in industry. At present, unlike its relationship with the aircraft industries, NASA is a net customer (rather than provider) of space technology. Development of NASA in-house expertise under this Pathfinder project is expected to change the relationship. Further, industry participation in actual flight mission development and integration is essential. Therefore, transfer of NASA developed technology is vitally important. It will enhance and complement the industry technology base which will add to the nations overall space R&T capability and will ultimately feed back into NASA programs.

7.5.2 Industry Teaming

A concerted effort will be made to involve industry in the Project activities via contracts, collaborative agreements, and other teaming relationships. Space R&T facilities and technology development testbeds will also be made available for industry use in the same way that aeronautical facilities are made available to the aeronautics community (See also Section 7.4).

7.5.3 Industry IR&D

Industry IR&D represents an important national space R&T investment. Project element managers at Ames, Langley, and Johnson will be encouraged to seek opportunities to review and influence the direction of related IR&D technologies which have direct applications to their R&T activities. This will serve to increase the leverage of technology investments in these areas and identify potential areas of future collaboration as well as avoid unnecessary duplication of effort. Industry representatives will be invited to participate in the annual review, described in Section 7.1.